COMBUSTION

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Heat Cycles and Relative Efficiencies
By F. H. ROSENCRANTS

Pulverized Fuel Firing Methods
By GEORGE W. CLENDON

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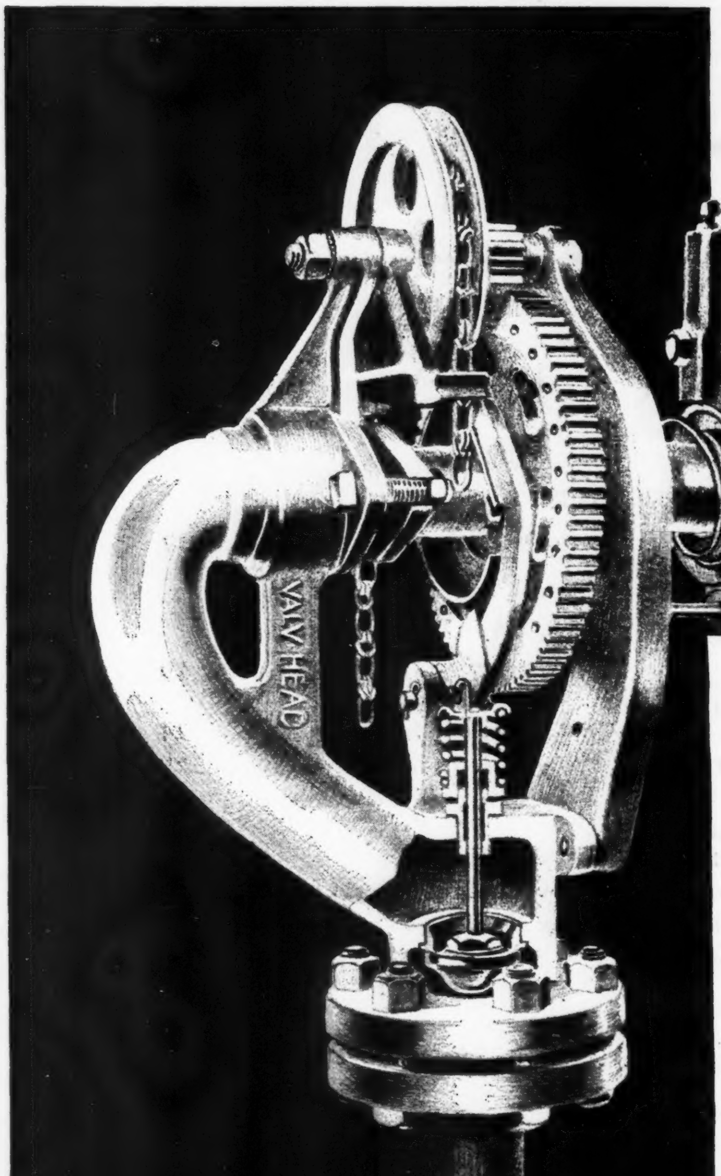
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COMBUSTION

VOLUME 2 MAY 1931 NUMBER 11

Thermodynamics Grows Up

JOSEPH H. KEENAN

THERMODYNAMICS which might be likened to a magician's bag into which two magic scrolls are dropped and from which innumerable gifts are withdrawn, will be the source of many wonders in the years to come. We see power engineering venturing into new fields, refrigeration developing apace, the flow of gases and liquids playing major parts in many industrial processes, and the rocket giving promise as a motive agent. To carry on these and other developments thermodynamics must be taught and taught well to our engineering students.

Methods of instruction are the last things to be perfected in a new science. Fundamental principles are thoroughly proved, experimental and analytical technique is developed and many engineering applications are made before any very satisfactory exposition of the subject is found. Those who contribute to these developments are either temperamentally unable to reach it, or, more probably, they are too busy. And perhaps many who otherwise might teach so love to bask in an esoteric atmosphere that they neglect to bring the subject down to a common sense earth. Like W. S. Gilbert's poem they hope that

" . . . . every one will say
As you walk your mystic way
If this young man expresses himself in terms too deep for *me,*
Why what a very singularly deep young man this deep young man must be!"

Newton's exposition of the law of gravitation remained a thing of mystery, except to a very small group of scientists, for a longer time than has (or will, if you please) Einstein's relativity. An engineer friend of a delightfully critical turn of mind recalls the early efforts of teachers to explain to him that it was Sir Isaac Newton who discovered why an apple fell to the ground. But to him it was all fuss and feathers. The real reason of course was that the stem rotted.

All of which drives home a fundamental principle of pedagogy which might be stated in the form of a definition: pedantry is the attempt to teach a subject for which the need is not obvious.

Thermodynamics is being better taught today because its teachers are taking this principle to heart. The old method of defining total heat, or enthalpy, as heat put in at constant pressure is a cart-before-the-horse method. Of what earthly use is such a quantity—or, why is not heat put in at constant temperature or at constant Gibbs potential equally entitled to a name? How much simpler and effective to make a first law analysis of the steady flow problem, than which there is no commoner problem in engineering, and to show that internal energy and the pv product always appear in summation. After solving six steady flow problems the student will, without prompting, think of this sum (U + pv) as a useful property of the fluid. Whence, total heat!

And what about entropy? Well behaved engineers who believe in immortality expect to receive an explanation of entropy along with their harp and halo. Our teaching methods have made it plain that the explanation is not for human minds. We can do quite well in our explanations of the second law if we stick closely to Carnot's hard headed reasoning. Why not start from there and show that a new property of the fluid which will clamp the second law restrictions on our analysis is sadly needed. If we do this well enough we shall inspire the student to reinvent entropy. And then thermodynamics will be really mature, and engineers will be more resourceful.

Joseph H. Keenan

Stevens Institute of Technology

EDITORIAL

Too Poor to Economize?

TO meet the spirit of the times, an age-old adage may be aptly paraphrased to read "Necessity is the mother of economy."

We hear much about the need of replacing obsolete equipment. And there is no question but that such equipment should be replaced wherever the funds are available and the economics of the situation indicate a satisfactory return from the investment. Today, however, in many organizations where the advantages of such replacement are recognized, the necessary funds are not immediately available to economize in that direction. But economy is imperative and cutting costs is reduced to doing the best that is possible with the equipment that is available.

Two important factors in overall steam plant efficiency are the condition of the equipment and the care and intelligence exercised in its operation. An organization that is too poor to keep its steam equipment in proper condition and which cannot afford to maintain a high standard of operation is suffering primarily from poverty of judgment for the savings effected by skimping on steam plant maintenance and operating personnel are trivial indeed when compared with the money that is squandered because of increased fuel consumption and the sacrifice of reliability.

Leaking baffles and settings, inadequate grate motion, and dirty boilers, combined with indifferent operation, exact an annual toll from American industry far greater than does obsolescence.

Steam costs must come down despite the fact that appropriations for new equipment are trimmed to a minimum. These conditions stand as a challenge to engineers and executives throughout all industry and every steam plant today is a proving ground on which are being tested the initiative, ability and loyalty of operating organizations in getting the best possible results from the apparatus that is entrusted to them.

The Small Plant

THIS issue of COMBUSTION contains the fourth and concluding article of Joseph Breslove's series entitled "Considerations in the Design of the Small Boiler Plant." This series of articles has presented an up-to-date survey of the subject which should serve to emphasize the opportunities which are available to small plant owners and operators for improving efficiency and raising the standards of practice in this important section of the field.

The advent and wide adoption of the small stoker, a comparatively recent development, has perhaps been the largest single factor contributing to progress in this field. It has gone forward with such rapid strides that the practical elimination of handfiring is now in sight. With the small stoker has come the incentive for cleaner and more efficient operation. Instruments which were considered a luxury a few years ago are now recognized as a practical necessity in checking every-day performance. Automatic control systems, and simple mechanical methods of handling coal and ash are finding economic justification.

The total result of this development is that thousands of plants from 500 hp. capacity down to the small, low-pressure heating plants are producing steam more economically and thus contributing to lower manufacturing costs. The very substantial percentage of our total coal production which is consumed in these plants is being used more efficiently with a consequent saving of enormous aggregate proportions.

The level of operating efficiency of the small plant is definitely on an upward trend and will continue to rise as more and more such plants take advantage of modern methods and equipment.

Adequate Instruments are Essential

IN the first attempts at measurement the units were selected because of their convenience. Thus, the cubit was the length of the forearm, the palm the width of the hand and the digit the breadth of the finger. For longer measurements the units were even less exact. There were the Roman pace, the Hebrew half-day's journey and the Chinese lih, the distance a man's voice could be heard in the open. The mille passus, a thousand paces, was the origin of the modern mile.

Crude indeed were these early measurements compared with the comprehensive system of international standards recognized today.

Efficient plant performance is dependent upon accurate measurements, for conditions must be compared with fixed standards before they can be analyzed and improved. The operation of the simplest steam plant involves the three variables, fuel, air and water, and their product—steam. Quantities, temperatures and pressures are factors in the process.

Adequate instruments are essential to the safe and efficient operation of any steam plant, and no other equipment will bring a larger and more certain return in proportion to the investment.

The operator who judges the condition of his fire by how it looks, who estimates the rate of boiler feed by the position of the valve handle and who guesses water temperature by the feel of the feed line, is not far in advance of those graybeards who, in 1374, defined the inch in English law as the length of "three barleycorns, round and dry."

Heat Cycles and Relative Efficiencies

By F. H. ROSENCRANTS
Advisory Engineer
Combustion Engineering Corporation
New York

To the power plant engineer who must select for his plant the heat cycle which will give the highest thermal efficiency consistent with reasonable reliability, the various heat cycles shown in the diagrams of this article will be thought provoking. While, in an article of this general character, any discussion of initial cost, of maintenance expense, and of availability of equipment is necessarily omitted, these factors must all be carefully considered for each particular case by the power plant designer, for the successful performance of a power plant is ultimately determined by the cost of producing a unit of electrical or mechanical energy rather than by the thermal efficiency of the cycle employed. The figures representing the final economic performance may well be in a different order from those given for the thermal efficiencies of the various cycles. It is only with such thermal efficiencies as envisioned in the diagrams of this article, however, that a start can be made toward an economic analysis of commercial possibilities for a particular case.

THE cycles A to G, shown in diagrams, pages 20 and 21, though not all inclusive, hit the high spots of progress since the war, and show future possibilities which are within our present range of vision.

Good practice in 1918 consisted of 240 lb. abs. pressure with 600 deg. fahr. total steam temperature (Cycle A). About 1923, 300 to 400 lb. pressure and 675 to 725 deg. fahr. temperature (Cycle B) received recognition. Cycle and station efficiency were given a further boost at this period by the adoption of multiple stage extraction of steam from the main turbine for feedwater heating and by the use of electric-driven station auxiliaries. A pressure and temperature at or near the upper limits of 1923 practice is still a popular choice by conservative engineers who seek a reasonably high efficiency with the maximum of simplicity and reliability.

The high pressure gas-reheat cycle, after passing through a transitory stage with an initial pressure of about 600 lb., stepped up to a throttle pressure of about 1200 lb. and a throttle temperature of about 720 deg. fahr. (Cycle D). At these levels a halting point has been established. At the moment there is little serious talk of any appreciable increase in pressure, but there is keen interest in higher temperature and a commitment slightly exceeding the 1200 lb. and 800 deg. fahr. limits of cycle D has been made.

Many engineers still look askance at the cost and complications of the high pressure-reheat cycle and are viewing with considerable favor the simple straight-through cycle with a pressure of 500 to 700 lb. and a temperature of 800 to 900 deg. fahr. (Cycle D) as having efficiency possibilities approaching the higher pressure reheat cycle with a considerable advantage of simplicity in construction and in operation. One commitment on a large scale for a plant of these characteristics has thus far been made. Others appear imminent. The most noteworthy European plants to adopt pressures and temperatures in these ranges without reheat are the Langerbrugge plant in Belgium with a pressure of 710 lb. gage and a temperature of 827 deg. fahr. at the throttle and the plant of the Synthetic Ammonia and Nitrates Ltd., at Billingham, England, with a pressure of 633 lb. gage and a temperature of 833 deg. fahr. at the throttle. The new Battersea plant, now under construction in London, will have a pressure of 600 lb. and a temperature of 850 deg. fahr. at the throttle.

The high pressure steam-reheat cycle has not been included in the series. The lower temperature reheat and the thermodynamic loss resulting from the degradation of heat in the high pressure steam used for reheating render the theoretical efficiency of the cycle somewhat less than the efficiency of the high pressure gas-reheat cycle. The only value of steam reheat is to dry the steam at the low pressure end of the cycle a sufficient amount to make the high initial pressure practical from an operat-

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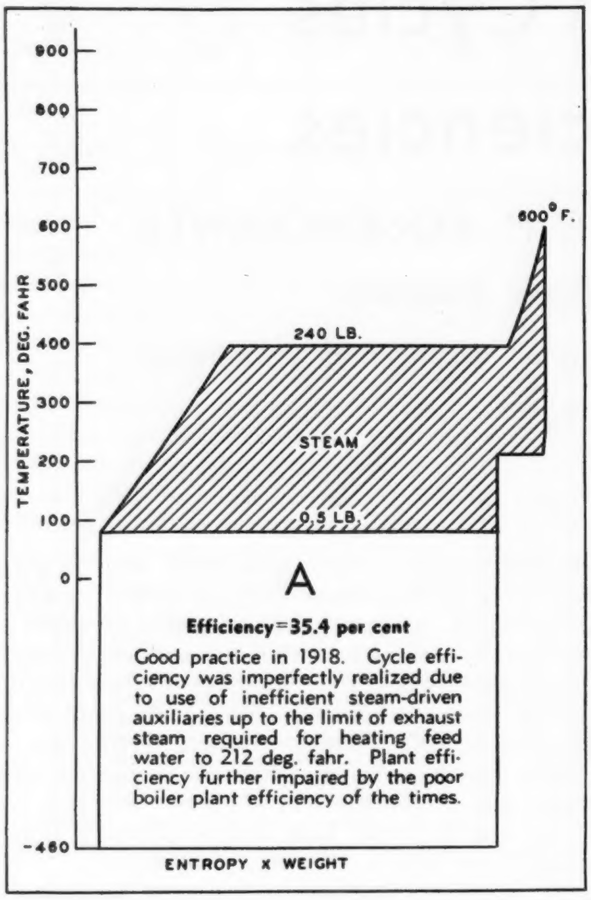
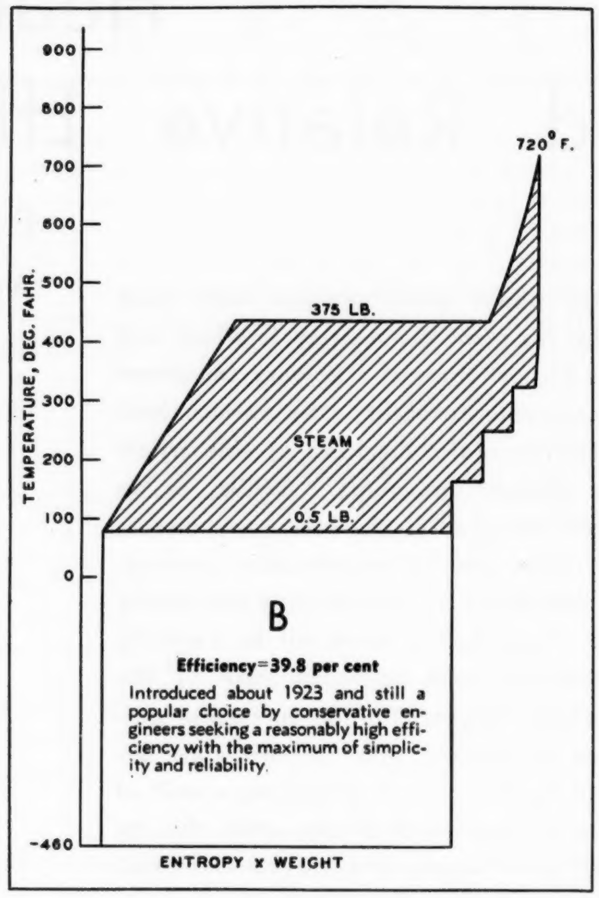
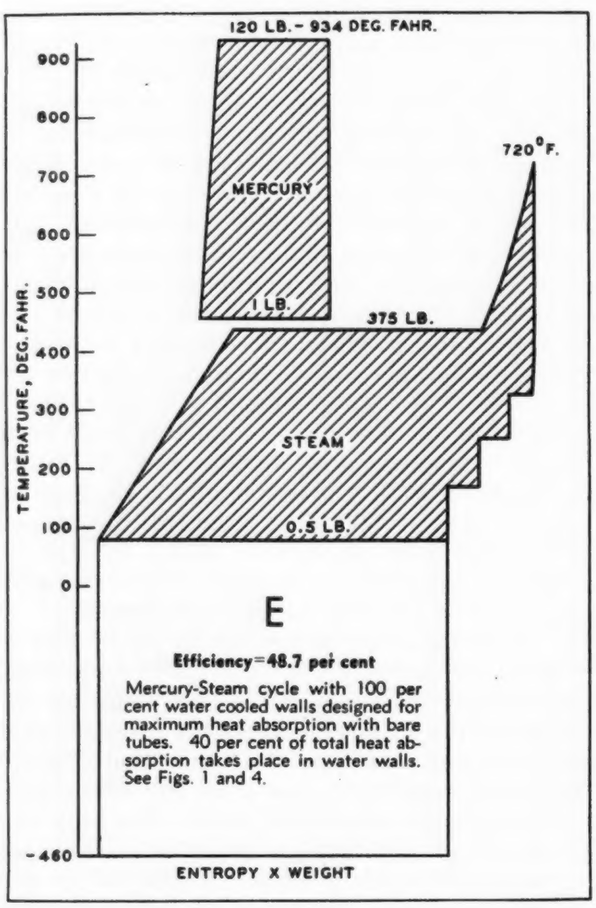
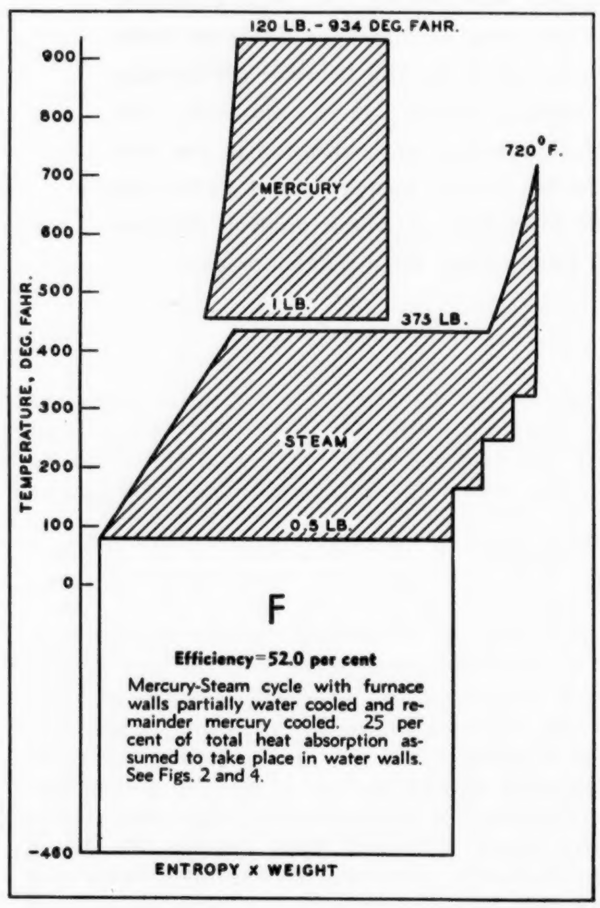
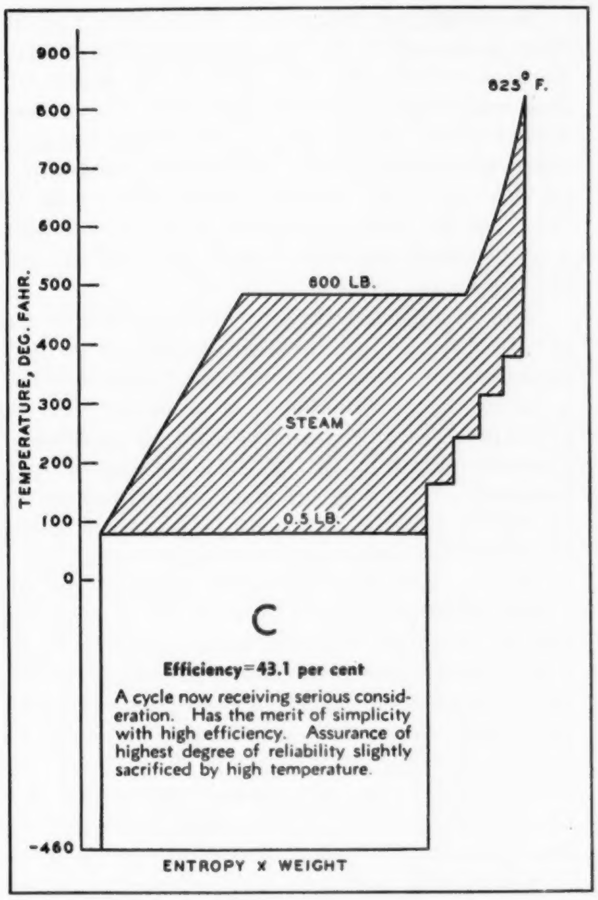


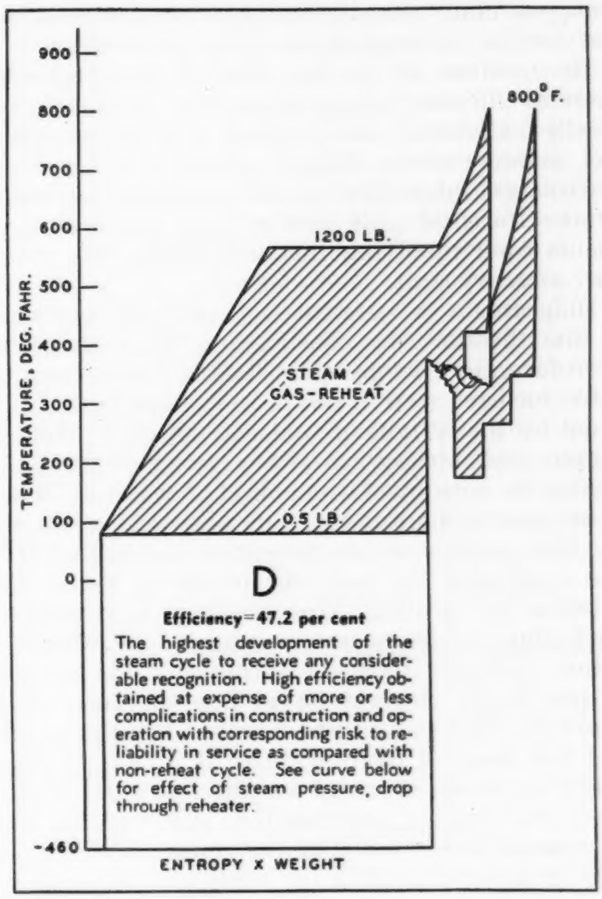


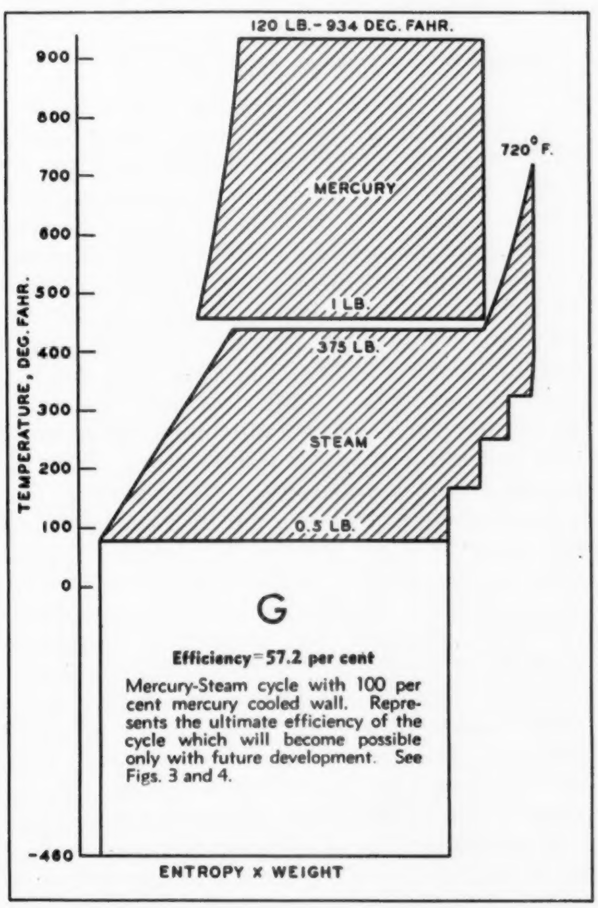




Heat Cycles and Relative Efficiencies—by F. H. Rosencrants







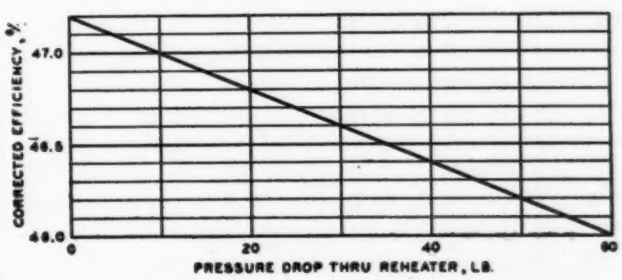


TABLE I. PLANT EFFICIENCIES

Cycle	Cycle efficiency—%	Turbine blading efficiency—%	Turbo-generator efficiency—%	Boiler plant efficiency—%	Aux. energy, % of generated	Overall plant efficiency—%	B.t.u. consumption per kw-hr. output
A	35.4	80	96.5	87.0	4.75	22.65	15050
B	39.8	80	96.5	87.0	4.65	25.50	13370
C	43.1	80	96.5	87.0	4.84	27.60	12340
D*	46.6	80	96.5	87.0	5.56	29.60	11500
E	48.7	80	96.5	84.7	3.63	30.70	11010
F	52.0	80	96.5	84.4	3.53	32.60	10450
G	56.7	80	96.5	84.0	3.12	36.00	9460

TABLE II. RELATIVE PLANT EFFICIENCIES

Cycle	A	B	C	D*	E	F	G
A	100	112.6	121.9	130.7	135.6	143.9	159.0
B		100	108.2	116.1	120.5	127.9	141.2
C			100	107.2	111.3	118.2	130.5
D*				100	103.8	110.1	121.7
E					100	106.2	117.3
F						100	110.4

* Assumes 30-lb. pressure drop througl reheater.

(*Continued from page 19*)
ing point of view. The greater simplicity in operation, especially when more than one boiler is used per turbine, is much in its favor, however.

Recognition of the fact that the limit of commercial efficiency of the steam cycle has been practically exhausted has inspired a keen interest in the mercury-steam binary cycles (E, F and G); an interest intensified by the successful operation of the Hartford unit and by two recent commitments each involving the installation of a 20,000 kw. mercury unit.

Diagrams A to G are based on one pound of steam at the throttle. In constructing these diagrams, therefore, the entropy quantities as taken from the table for each step in the process have been multiplied by the weight of material affected. For example, the entropy at the beginning of the liquid line is the entropy of one pound of water at 79 deg. fahr. (corresponding to 0.5 lb. pressure) multiplied by that portion of one pound of condensaie from the condenser for each one pound of steam supplied at the throttle. This weight is augmented at each stage of feedwater heating by the weight of steam extracted from the turbine for the purpose. A practically straight liquid line in place of the more familiar curved line results. Beginning with the last stage of heating, there is a full pound of water or steam involved for the rest of the liquid line, and for the vaporization, superheating, and expansion lines down to the point at which the first steam is extracted for feedwater heating. At each stage of steam extraction, total values of entropy of the diagrams are successively reduced by an amount obtained by multiplying values of tabular entropy by the weight of steam extracted.

The area of the diagram circumnavigated in the process accurately represents the maximum possible heat converted into work per lb. of throttle steam. The area beneath the 0.5 lb. exhaust line accurately represents the heat rejected to the condenser. Both check accurately with values derived from the Mollier diagram. To retain this feature for diagram D requires shifting the area representing the high pressure bleed point to the left to avoid overlapping the area representing the other three bleed points after reheating. With the changing weight of steam involved during the expansion, points on the expansion line are meaningless for indicating the state of the steam as regards degree of superheat or moisture.

It is of interest to note that the moisture content at the turbine exhaust for each of the cycles, on the assumption of 80 per cent turbine blading efficiency, is as follows: Cycle A—11.5 per cent; B—10.3 per cent; C—9.8 per cent; D—7.9 per cent; E, F, and G, the same as B: i.e., 10.3 per cent.

The mercury-steam cycles are based on one lb. of throttle steam to the steam turbine. The quantities of mercury involved are as follows:

For cycle E—4.41 lb.
For cycle F—6.28 lb.
For cycle G—10.0 lb.

All values as applying to mercury are taken from the table by L. A. Sheldon of the General Electric Company.

In compiling Table I, a lower boiler plant efficiency is assumed for the mercury-steam cycle than for the steam cycle due, first, to the lower final flue gas temperature practicable with the steam cycle and, second, due to the higher radiation loss in the mercury-steam cycle. Final flue gas temperatures of 325 deg. fahr. for the steam cycle and 400 deg. fahr. for the mercury-steam cycle are assumed with a consequent advantage of 2 per cent in efficiency for the steam cycle.

It is recognized that by using a lower gas temperature range for the steam superheater and a correspondingly larger superheater and also by using a larger air preheater that a boiler efficiency of perhaps 2 per cent higher could be obtained for the mercury-steam cycle. With a corresponding extravagance in the use of heat absorbing surface on the tail end of the steam units, however, the margin of 2 per cent difference would be retained.

All exposed high pressure parts of the mercury boiler including the whole of the furnace cooling surface for the 100 per cent mercury cooled job will be at a temperature of approximately 1000 deg. fahr. compared with a temperature of about 450 deg. fahr. for the water cooled surface; hence, a higher radiation loss may be anticipated. This difference might be compensated for by a sufficient increase in insulation for the mercury job. The efficiencies of Table I, however, are based on the following extra losses due to radiation as compared with the steam cycle:

Cycle E—0.3 per cent
Cycle F—0.6 per cent
Cycle G—1.0 per cent.

In calculating the auxiliary energy consumption, relative correctness as between the various cycles rather than precision as applying to any one of them has been the aim. Energy consumption of auxiliaries associated with the combustion process has been assumed to be directly proportional to the station heat consumption per kw-hr. output, an assumption which somewhat favors the higher pressure steam cycles and possibly the mercury-steam cycles as the draft losses are likely to be greater for the same efficiency than for the cycles operating at lower temperature. Energy consumption of condenser auxiliaries has been assumed directly proportional to the heat rejected to the condenser per kw-hr. of station output. Energy consumption of the boiler feed pumps has been assumed directly proportional to the weight of water pumped per kw-hr. of station output multiplied by the boiler operating pressure. The mercury from the mercury condenser-boiler has been assumed to run back into the boiler by gravity. For miscellaneous service, an auxiliary energy consumption of .005 kw-hr. per kw-hr. station output has been assumed for all cycles.

A glance at Fig. 4, derived from cycle diagrams E, F and G, for the mercury-steam cycles and at Table 2 indicates the desirability of a mercury cooled furnace. In the development of such a fur-

nace, the designer is confronted with interesting problems. Assuming the cooling surface to be made up of vertical tubes connected into horizontal headers at top and bottom in a manner similar to that with which we are familiar in water wall construction the pressure in the bottom header will be 5 to 6 lb. higher than the pressure in the mercury drum for each foot of height between the bottom header and the mercury surface in the drum. With only a moderate furnace height and a drum pressure of 120 lb. absolute, the boiling temperature of the mercury corresponding to the pressure in the wall tubes will be between 1050 and 1100 deg. fahr. The wall face next to the furnace will, of course, be at higher temperature.

The heat required to vaporize a pound of mercury at 120 lb. abs. pressure is 116.4 B.t.u. The heat to evaporate one pound of water at say, 600 lb. abs. pressure is 729 B.t.u. This would seem to indicate roughly that 6.25 lb. of mercury will have to be circulated to do the same amount of furnace wall cooling as one pound of water. Assuming the weight of mercury to be 13 times that of water, the volume of mercury circulation would appear to be

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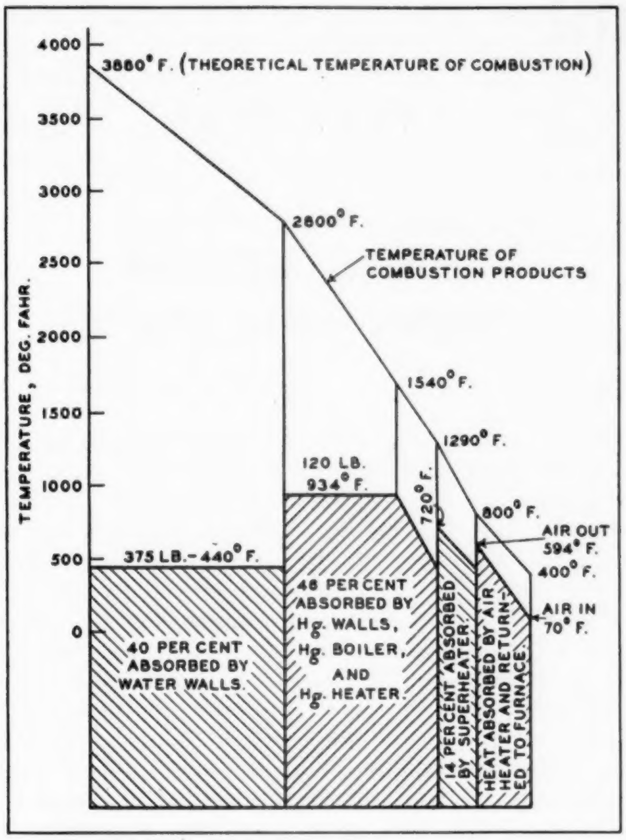


Fig. 1—Heat distribution in boiler unit for Cycle E

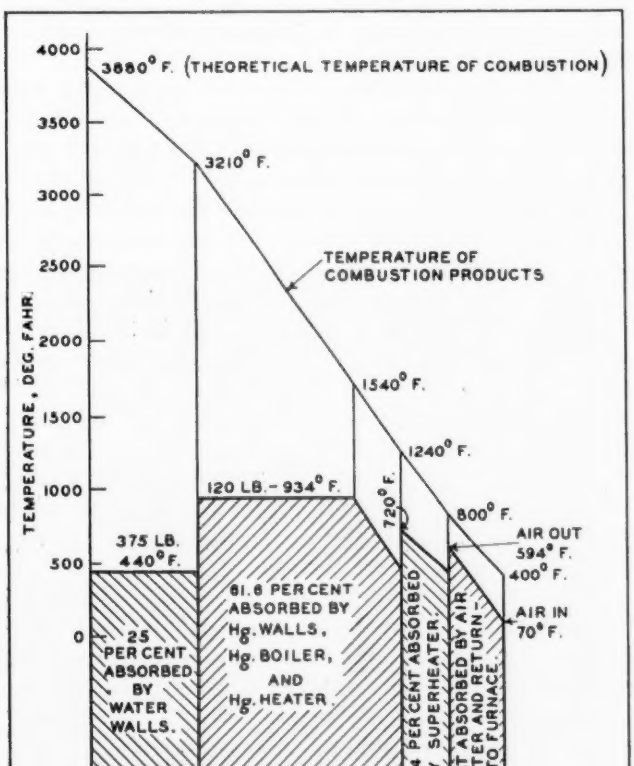
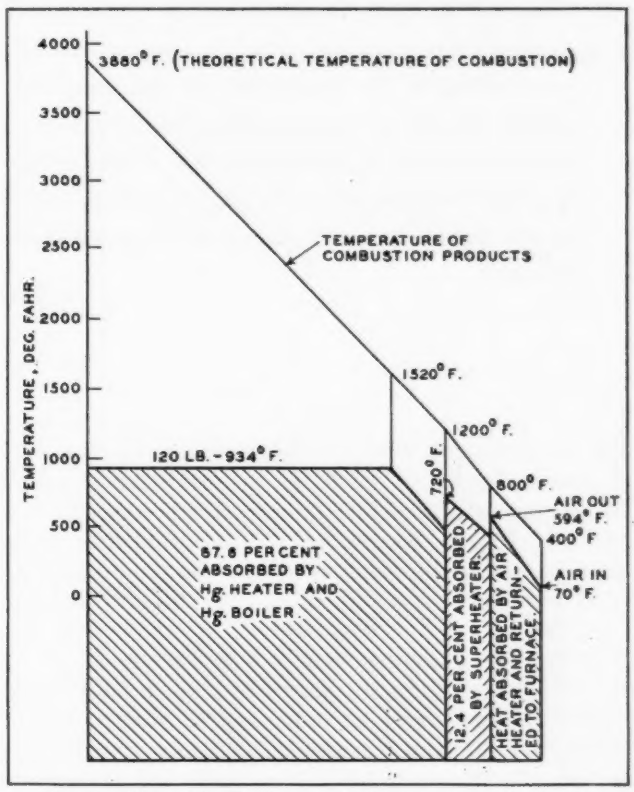


Fig. 2—Heat distribution in boiler unit for Cycle F



Fg. 3—Heat distribution in boiler unit for Cycle G

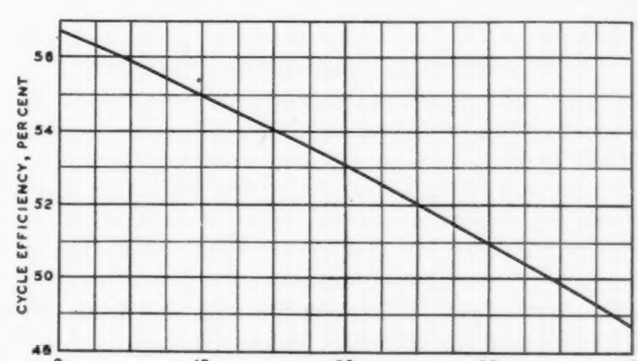


Fig. 4—Per cent of total heat of combustion absorbed by water cooled furnace walls in the mercury-steam cycle.

Considerations in the Design of the Small Boiler Plant

PART FOUR

By
JOSEPH BRESLOVE
Consulting Engineer, Pittsburgh

In this, the fourth and last article of his series, Mr. Breslove presents cost data and discusses the design problems of several existing plants. In some cases the work involved the addition of new units and in others, complete new plants were installed. In each instance, the existing conditions and the problems to be met are outlined . . . . These practical applications of the author's theories on the design of small plants, as presented in previous articles, form a fitting conclusion to his discussion of the subject, which has been marked throughout by comprehensiveness of treatment and a thoroughly practical grasp of the fundamentals as well as the detailed ramifications of the problems involved.

•

IT would seem that the keynote in the design of the small boiler plant is conservatism but with an appreciation of the latest improvements in the art. If in its design, correct engineering is applied it can be built at a reasonable price and operated with fair economy so as to result in a satisfactory return on the investment. It is well to bear in mind the excellent work done for the large station during the recent years but one's zeal for the extraordinary must be tempered to suit the conditions surrounding the smaller station. A standardized boiler house is hardly feasible but certain elements in the design may well be considered common to all.

Having briefly mentioned in the preceding articles in this series the salient features guiding the design of the small boiler plant, we may pass to a number of special cases illustrating the various points brought out in the discussion. These have been chosen from a number of industries varied in their requirements for steam or electricity. The figures covering the costs were those actually contracted for or taken from bids on the equipment. They represent fairly recent expenditures and therefore apply to present day costs.

Pittsburgh Spring and Steel Company

This was an obsolete boiler plant containing six 150 hp. old type combination marine and tubular boilers supplying steam for engine generator sets, building heating, oil heaters, and forging hammers used in the production of heavy railroad springs and allied equipment. Some of these boilers were hand fired and the remainder served by an early design of Combustion Engineering, Type E stokers and an engine-driven draft fan. Coal was wheeled from the storage pile onto the boiler room floor and shoveled into the stoker hoppers or furnaces by hand. The average load varied from 500 to 1000 hp. with high peaks during the operation of steam hammers. It was, therefore, decided to install 2—500 hp. units and such auxiliary apparatus as would result in an up-to-date economical plant. It was felt that the entire load should be carried on one boiler at all times and the installation was carried out accordingly.

Because the building was low and wide, horizontal, longitudinal drum, straight tube boilers were chosen, these fitting themselves into the available space to the best advantage. Two of the old boilers were removed to provide space for the new units and, although it was not an easy task, the plant was kept going with the four remaining boilers. The longitudinal drum boilers could be shipped assembled ready for installation on the foundations which was a decided advantage in this case. Individual steel stacks were chosen. Side dump, underfeed stokers, requiring no basement, were selected and a steam jet ash conveyor installed to deliver the ashes to a hollow tile ash tank in the yard. The front row of boiler columns were designed to carry half the coal bunker load and the roof structure over the bunker.

With the new arrangement, coal is taken from a large storage pile in the works yard where it is delivered by railroad cars. A belt conveyor carries it through an adjacent building to the bucket elevator alongside the boiler room. See Fig. 3. The bunker has a capacity of 150 tons.

The auxiliary equipment comprises an open feed water heater, two duplex boiler feed pumps and a turbine-driven draft fan. It is the intention to add a motor-driven draft fan at a later date but so far

operating conditions have not warranted it. Each boiler is furnished with a steam flow meter indicating the horsepower and recording the flow in pounds, also a pointer-type draft gage. A boiler-pressure regulator operates on the throttle of the fan turbine but is not hooked up to the stack dampers which are hand-controlled. It was felt that additional instruments or controls were not warranted and could not pay dividends. The coal consumption was cut down more than 1/3 with the new equipment and the operating crew reduced to one man per shift.

The individual items and their cost follow:

COST OF BOILER PLANT
PITTSBURGH SPRING & STEEL COMPANY

2—500 hp. Heine horizontal boilers—erected, including Heine soot blowers	$18,000.00
Foundation and brickwork	8,308.00
2—60 in. x 125 ft. steel stacks with breeching—erected	3,880.00
2—Stokers, Type E—erected	6,845.00
Coal handling and storage bin including extension over present building, etc.	7,300.00
Steam jet ash conveyor and ash tank in yard	4,300.00
1—Sturtevant draft fan with turbine drive	1,433.00
Open feed water heater and relief valve	1,509.00
Piping and valves (boiler room only)	7,122.00
Changes in boiler house building and removal of old boilers	2,500.00
1—10 x 6 x 12 Worthington, duplex B. F. pump (one pump on hand)	770.00
2—Fisher excess pressure pump governors	90.00
2—Copes boiler feed water regulators	247.00
2—Cochrane flow meters	510.00
2—Draft gages	140.00
Pipe covering	450.00
	$63,504.00

Johnson Bronze Company, New Castle, Pa.

This Company is engaged in the manufacture of bronze bushings for the automotive trade, bearings for railroad cars and similar products. Electric power is purchased from the local public utility but a boiler plant is required to provide steam for the heating load which consists of unit heaters and wall radiation. Continued increase in manufacturing capacity and modernization of the plant necessitated a new boiler installation.

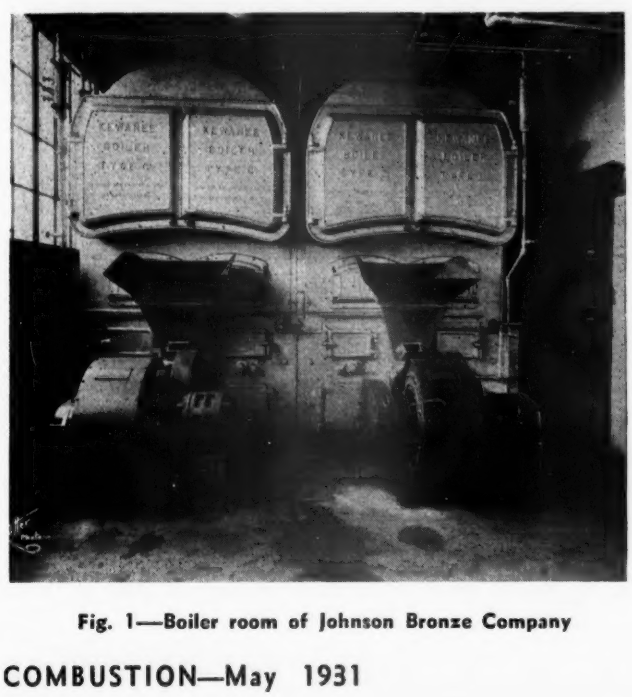


Fig. 1—Boiler room of Johnson Bronze Company

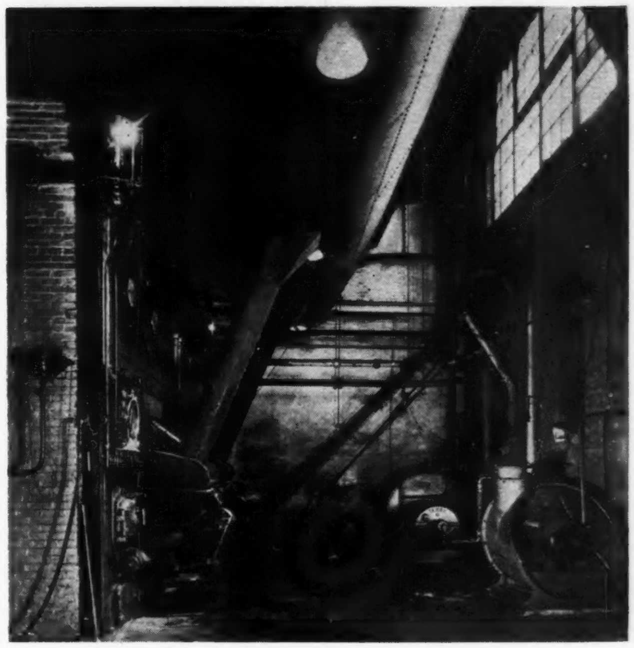


Fig. 2—Boiler room of Hardie Bros. Company showing forced draft fan and steam jet ash conveyor.

The plant installed is an excellent example of the modern trend away from hand labor and towards stoker firing in the low pressure heating field. Space requirements were at a premium but it will be noted from Fig. 1 that both the boilers and stokers are accessible. Coal is fed into the hoppers manually but there is in contemplation a monorail hoist and bucket system which will take coal from the storage pile adjacent to the boiler room and deliver it to the stoker hoppers. The usual heating boiler base carrying the shaking grate and ash compartment was removed and the boiler mounted on brickwork to allow for the increase in furnace height and volume essential to stoker firing.

COST OF BOILER PLANT
JOHNSON BRONZE COMPANY

2—No. 768 Kewanee 2500 sq. ft. radiation heating boilers, each 182 hp.	$ 4,092.00
Foundation and brickwork (part of building contract) approx.	1,200.00
2—Riley riflex drive stokers with fans and motors	4,063.00
1—54 in. x 110 ft. steel stack and breeching	1,940.00
	$11,295,00

Hardie Bros. Company, Pittsburgh, Pa.

This company manufactures a complete line of candy products reaching as high as 150,000 lb. per day. They are large users of high pressure steam for cooking and low pressure steam for dry rooms, hot tables, air conditioning, heating coils, building heating, etc. They found it necessary to build a new factory and, consequently, free scope was given in the design of the boiler plant within the ordinary building range and unhampered by the retention of old equipment and buildings.

The coal handling equipment consists of a track hopper, a 24 x 24 single roll crusher, bucket eleva-

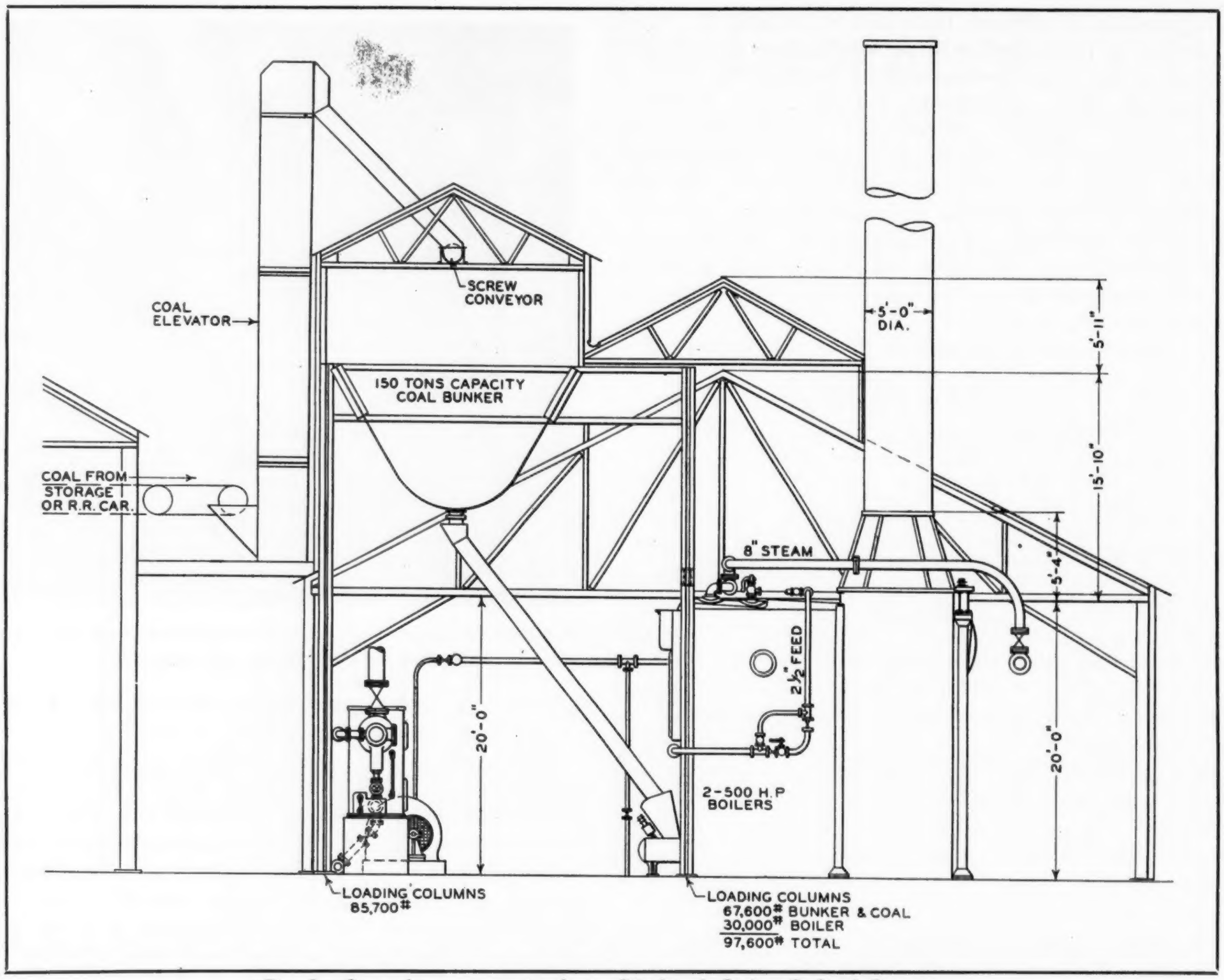


Fig. 3—General arrangement plant—Pittsburgh Spring & Steel Company

tor, screw conveyor and a 150 ton capacity parabolic steel bunker 50 ft. in length, 17 ft. wide and 10 ft. deep, built the full length of the boiler room so as to accommodate three boilers, only two being installed at present. A double screw conveyor feeder is installed over the top of the bunker instead of the usual single screw thus making it possible to take advantage of the entire storage capacity of the bunker notwithstanding the low head room. This is shown in Fig. 4.

The ash hopper is a concrete lined steel tank supported on a nest of beams extending into the second row of building columns and without the usual supporting posts which building restrictions prohibited. The boiler room is in a sub-basement and the steam jet ash conveyor is 140 ft. long with 4 bends. It leaves the firing floor at an angle of 45 deg., (See Fig. 2) extends vertically upwards 72 ft. to the second floor ceiling of the building and horizontally out to the tank. This particular installation illustrates very well the flexibility of this type of equipment.

Horizontal, cross drum boilers were best fitted for the low head room and basement conditions. Single retort stokers eliminated the necessity for an additional basement. A 6 ft. 6 in. x 150 ft. brick stack located in the engine room has sufficient capacity for 3—350 hp. boilers. The speed of the steam turbine-driven draft fan is controlled from a boiler pressure regulator and the furnace draft

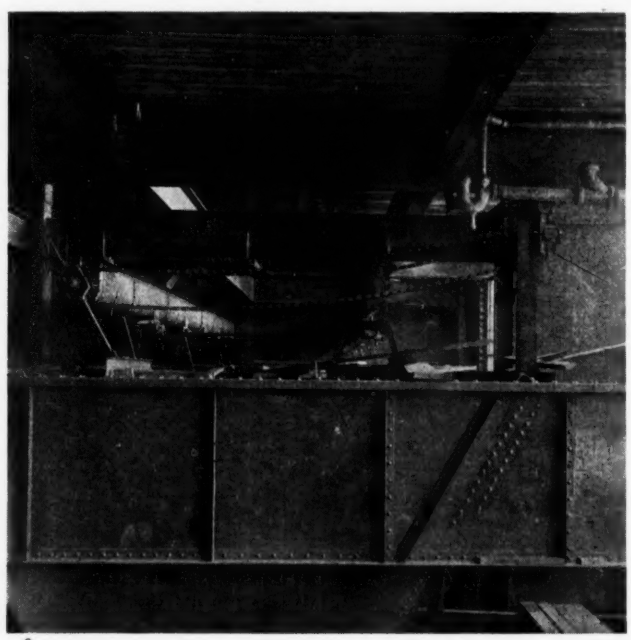


Fig. 4—Double screw distributing conveyors in plant of Hardie Bros. Company

through a Carrick control. During the normal operating day one boiler at 150 to 175 per cent rating carries the entire plant but during the rush season of winter and spring the two boilers are in service. The single draft fan has been in continuous service for about seven years without extraordinary repairs or shutdown. A motor-driven fan will be added when the third boiler unit is installed.

This is an unusually complete plant operating with excellent economy; non-condensing steam engine and turbine generator units exhaust into the low pressure heating and process steam main. The returns are handled by a Nash vacuum pump and discharged into an open feed water heater of extra large storage capacity. During the heating season some extra high pressure steam is required but at other times there is just sufficient exhaust for process and heating steam.

As a matter of interest outside the boiler room, a manufacturing plant of this character requires hot and cold water distribution, high and low pressure steam, pumping equipment for handling glucose and sugar products, heating, refrigeration, and air conditioning, cold air for cooling candy products and hot air for curing and heating. A combination of steam-driven and motor-driven refrigerating machines permits desirable heat balance. Many small alternating current motors are in use and the power factor would be very low; therefore, a rotary condenser is employed for its correction.

COST OF BOILER PLANT
HARDIE BROTHERS COMPANY

2—365 hp. Springfield cross drum boilers—erected..	$10,975.00
Vulcan soot blowers	508.00
Foundations—(part of building construction) approx.	5,000.00
Boiler brickwork	2,550.00
1—6 ft. 6 in. x 150 ft. brick stack	3,785.00
Steel breeching	995.00
2—Type E stokers—erected	4,770.00
Steam jet ash conveyor	1,297.00
Open feed water heater & relief valve	2,172.00
Concrete lined steel ash tank with gate	1,435.00
1—Green fan and terry turbine	1,219.00
Piping and valves—boiler room only	6,600.00
2—Copes feed water regulators	231.00
2—Fisher excess pressure pump governors	58.00
2—Draft gages	140.00
Pressure regulator	269.00
Carrick furnace draft control	250.00
2—7½ x 4½ x 6 Worthington duplex B. F. pumps...	736.00
1—48 in. x 60 in. cast iron blow off tank	151.00
Pipe covering	800.00
	$43,941.00

Crandall, McKenzie & Henderson

This Company, one of the large dyeing and dry cleaning establishments, found it necessary to provide for additional boiler capacity, the 150 hp. hand fired h.r.t. boiler which has served the plant for years having become inadequate. Since the plant was located within the city limits, smokeless operation was imperative. Space restrictions were severe and it was with difficulty that room was found for another 150 hp. boiler.

The arrangement of this plant is such that the smoke breeching extends to the ceiling and there was only room for an air space between the boiler and building walls. The soot blower headers are located just below the breeching, this installation being an example of the application of mechanical soot blowers to an h.r.t. boiler. Fan control and a steam flow meter are mounted on the wall. Coal is delivered by truck to the firing floor and shovelled into the stoker hopper, mechanical handling not being justified. The installation is another example of stoker firing for small boilers. The increase in capacity and reduction in fuel cost justified the cost of stoker.

COST OF BOILER PLANT ADDITION
CRANDALL, McKENZIE & HENDERSON

1—150 hp. Coatesville, h.r.t boiler	$ 1,925.00
1—Riley side dump stoker	2,032.00
Foundation, brickwork & erection	2,945.00
Vulcan soot blower	168.00
Blow off tank	92.00
Boiler breeching	458.00
Steam and water piping	2,160.00
Williams boiler feed water regulator	119.00
Worthington 6 x 4 x 6 boiler feed pump	166.00
Cochrane flow meter	283.00
Smoke indicator	50.00
	$10,398.00

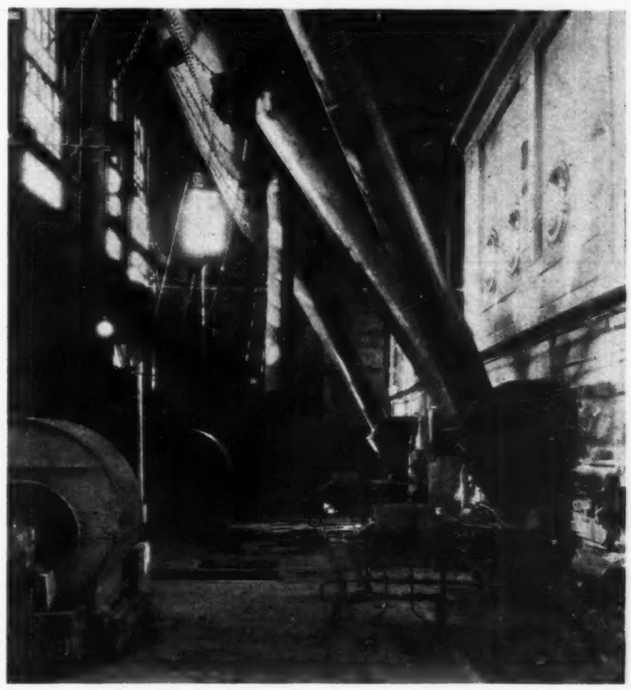


Fig. 5—Completed plant of Union Drawn Steel Company

Union Drawn Steel Co., Beaver Falls, Pa.

The Beaver Falls Plant, of this Company was one of the pioneers in the production of cold drawn steel products such as shafting, special shapes, wire rods, etc. Its operations require large quantities of steam for pickling and heating. Electric power is purchased but under certain conditions some of it is generated in non-condensing steam engines which exhaust into the low pressure mains, the exhaust being used for heating.

The original boiler house, consisting of six horizontal water tube boilers, fired with chain grate stokers, had outlived its usefulness and it was desired to replace the old boilers with new units. Two boilers, one of 500 hp. and the other of 600 hp. were

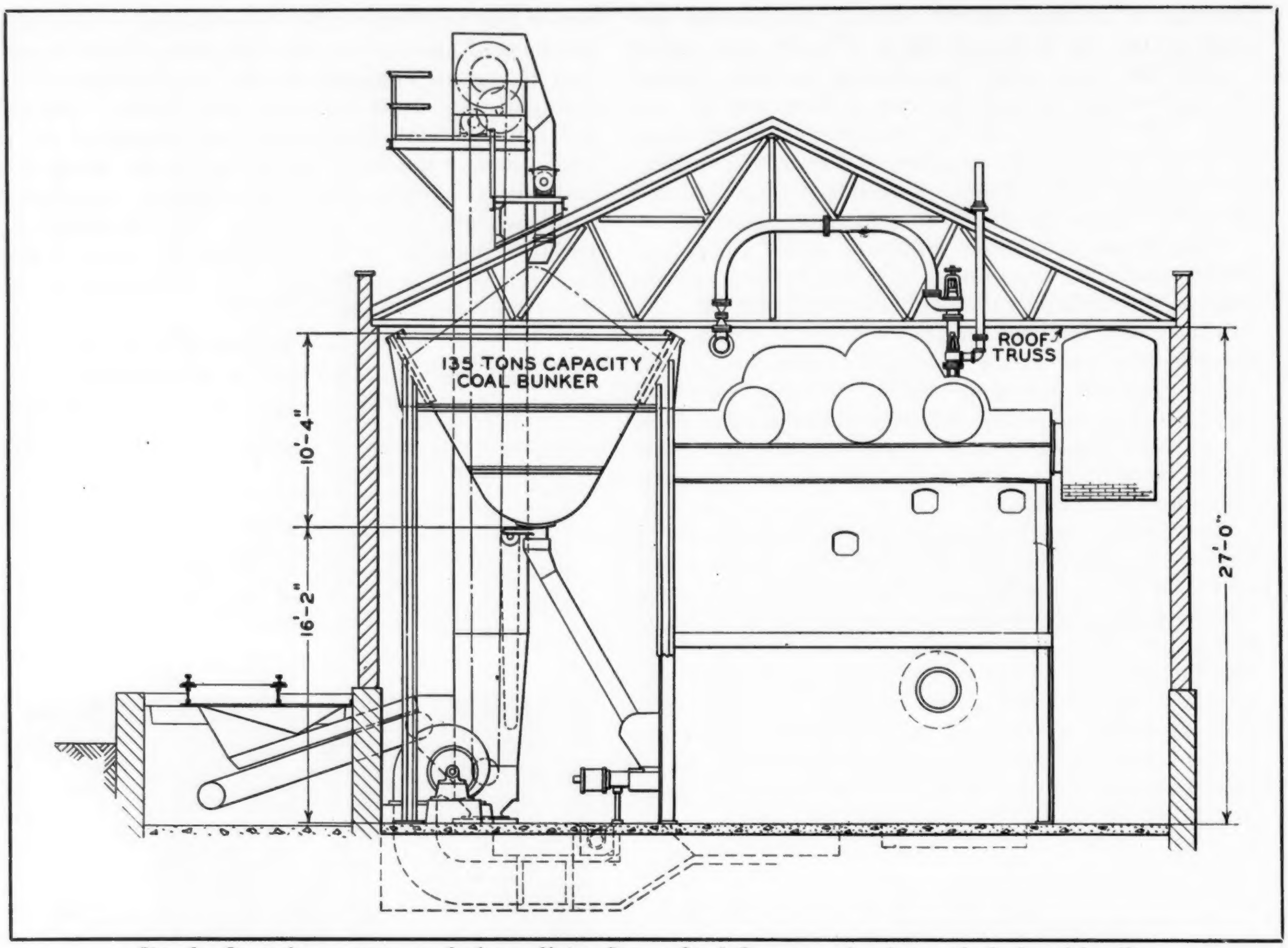


Fig. 6—General arrangement of plant—Union Drawn Steel Company, showing method of coal handling

decided upon. One of these will carry the entire load with the other in reserve. The larger boiler will be in service during the winter heating season. Babcock & Wilcox sterling type boilers with Westinghouse stokers comprise the main units.

The layout is interesting as showing what can be done with a low building without alterations to the structure. It will be noted from Fig. 6 that the coal distributing screw, taking coal from the vertical elevator, is installed outside the building eliminating the necessity for increased height of roof and making it accessible for inspection and repairs. Fig. 5 shows the completed plant. Two draft fans are installed, one turbine driven and the other motor driven. The change over from the old equipment to the new was accomplished without a shutdown and the resulting plant is a modern and efficient boiler room. The boilers are suitable for high pressure and superheat for future operation when a private electric generating station is contemplated.

Follansbee Bros. Steel Co., Toronto, Ohio.

The Follansbee Plant at Toronto, Ohio, is one of the smaller steel mills producing high grade sheets for deep drawing, automobile bodies, etc., and comprises a complete mill from the production of the open hearth steel to the finished sheet. The power plant was described in detail in the July 25th, 1922, issue of *Power*. A description of this boiler plant seems a fitting closure to the foregoing "considerations," for a comparison of the layout with a similar capacity unit of today clearly shows the trend of modern design.

In Fig. 7 is shown the boiler room which con-

(*Continued on page 39*)

Fig. 7—Boiler room of Follansbee Bros. Company. Note arrangement of fans.

Composition and Heating Value of Fuels*

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This is the first of a group of four articles on the properties of fuels and combustion calculations. In the present article, the author discusses the methods of determining the composition and heating value of solid, liquid and gaseous fuels, the conventional terms used, and the significance of these methods and terms as they apply to combustion calculations. Of particular interest is the discussion of the factors which influence the heating value of fuels and a method developed by the author for determining the lower heating value from the upper heating value. This article provides a basis for a treatment of combustion calculations to be given in the succeeding articles.

IN combustion calculations, it is customary to consider a fuel as composed of a small number of chemical elements or compounds. Thus, fuel gases are analyzed to determine the volumetric percentages of carbon monoxide, methane, etc., and the proportion of these chemical compounds is taken as the starting point for calculating the heating value of the gas, the amount of air required for combustion, the composition of the products of combustion, etc. In solid and liquid fuels, however, the components are much more complex and numerous than in gaseous fuels; consequently, it is a simpler matter to determine by chemical analysis the weight percentages of carbon, hydrogen, sulphur, nitrogen and oxygen in addition to moisture and ash in the fuel, than to find the nature and proportions of the chemical compounds present. For such fuels, the amount of air required for combustion and the composition of the products of combustion are therefore based on the weight percentages of the chemical elements in the fuel.

The heating value of a solid or liquid fuel may be calculated with a greater or less degree of accuracy from its chemical analysis, depending upon the character of the fuel, but it is always preferable to determine its heating value experimentally in a suitable calorimeter. For certain gaseous fuels, experimental determinations are likewise preferable to calculating their heating values from their compositions.

As the compositions and heating values of fuels are utilized in combustion calculations for analyzing the performance of existing furnaces and for predicting the performance of new designs, it is important to grasp the significance of the various terms used and of the conventional and exact methods of making the determinations. These are discussed in the present article as a basis for a treatment of combustion calculations to be given in articles to follow.

Chemical Analysis of Solid and Liquid Fuels

In the ultimate analysis of solid and liquid fuels, carbon and hydrogen are determined in one operation by burning a sample of the fuel in a stream of oxygen and air which has previously been dried and purified of carbon dioxide. The water vapor and carbon dioxide formed from the hydrogen and carbon in the fuel are absorbed respectively by sulphuric acid and by a solution of caustic potash. These are weighed before and after the operation to find the weights of water vapor and carbon dioxide absorbed, from which the percentages of hydrogen and carbon in the fuel are calculated. Sulphur and nitrogen in the fuel are separately determined by appropriate chemical methods. The amount of ash is found by weighing the residue remaining after igniting and burning off the combustible matter at a temperature between 700 and 750 cent. For a solid fuel, the moisture is determined by the loss of weight when a sample is dried in an over for one hour at 105 cent. The moisture in fuel oil is found by adding gasolene and then distilling and collecting the condensed vapor which separates into liquid layers of water and gasolene because water and gasolene are not appreciably soluble in each other. Finally, the percentage of oxygen in the fuel is calculated by subtracting the sum of the percentages of the other constituents from 100 per cent.

The percentage thus obtained for oxygen is evidently affected by errors in all the other determinations, and especially by the changes in weight which occur in the ash upon igniting and burning the combustible matter. Thus, the iron pyrite in the ash changes to ferric oxide which weighs more than the iron present but less than the original iron pyrite. Also, there is always a loss of water of composition from the clayey and shaley constitu-

ents of the ash and of carbon dioxide from the carbonates present. Sometimes, a "corrected ash" is reported in which allowances have been made for these errors. Usually, however, such corrections are not attempted because they require a chemical analysis of the ash.

The chemical analysis of a sample of fuel as above described, is not made upon the sample as received in the laboratory, but the sample is first air dried so that the moisture therein will be in equilibrium with that in the atmosphere and therefore not change appreciably during the grinding and other operations required in the analysis. The loss of moisture in air drying the sample is an indication of the reduction in moisture that may be readily accomplished in drying the fuel. The results of the analysis upon the air dried sample must be reduced by calculation to the fuel "as received." Sometimes the results of the analysis are also reduced to "moisture free" fuel and to "moisture and ash free" fuel.

Other Tests on Solid and Liquid Fuels

In addition to the ultimate analysis, other tests are often made upon solid and liquid fuels which indicate something about the composition of the fuel. Thus for coal and coke, a proximate analysis is made in which in addition to moisture and ash, the "volatile matter" is determined by the loss in weight when a sample is heated for seven minutes in a closed crucible at 950 cent. The combustible remaining in the crucible is designated as "fixed carbon." The relative amounts of volatile matter and fixed carbon may be used as a guide to determine the furnace volume required to burn the volatile matter above a grate on which the coal is fired or the total furnace volume necessary in the case of pulverized coal to nearly complete the combustion of the fixed carbon, but they do not directly enter into combustion calculations except when the percentage of hydrogen in the coal is determined therefrom as explained in U. S. Bureau of Mines Technical Paper 197 or the heating value of the coal is estimated therefrom as explained later in this article. Likewise, distillation tests and viscosity determinations upon liquid fuels, while important in providing data for obtaining the best combustion conditions, only indirectly enter into combustion calculations. Even the flash point determination for fuel oil is important only in connection with safe storage of this fuel. The density determination upon petroleum, however, is of direct application in indicating the heating value of that fuel as explained later.

Analysis of Gaseous Fuels

The apparatus commonly used to analyze gaseous fuels is an extension of that described in the article on the "Thermal Properties of Gaseous Mixtures." The fuel gas is first passed through a solution of caustic potash to absorb carbon dioxide. It is then passed through fuming sulphuric acid or through saturated bromine water to absorb the illuminants, or heavy hydrocarbons. After oxygen and carbon monoxide are absorbed by the usual reagents, hydrogen is oxidized by passing the remaining gas over copper oxide at or slightly below 300 cent. and note taken of the contraction in volume due to condensation of the resulting water vapor. Finally, methane and ethane are determined by admitting a measured volume of oxygen, igniting the mixture by means of an electrically heated platinum coil and then noting the contractions due first to condensation of the resultant water vapor and second to absorption of the resultant carbon dioxide in caustic potash solution. From the values of these two contractions, the relative amounts of methane and ethane are calculated. If the constituents as above determined do not add up to 100 per cent, the difference is taken as nitrogen.

The illuminants consist mostly of ethylene and benzene but also include propylene, butylene, acetylene, toluol, etc., if these are present in the gas. The relative proportions of these unsaturated hydrocarbons can be determined by fractionation at very low temperatures, but the procedure is too involved for use in ordinary analyses. Unless additional information is available as to the composition of the illuminants, they may be assumed to be ethylene (C_2H_4) in combustion calculations.

The percentages of methane and ethane determined by the analytical procedure explained above are usually not the true proportions of these constituents in the gas, but are the equivalent of all the saturated hydrocarbons which may be present, propane, butane, pentane, etc., as well as methane and ethane. These saturated hydrocarbons could be determined by fractionation at very low temperatures. All the properties, however, which affect the gas as a fuel, namely, heating value, specific gravity, air required for combustion and composition of products of combustion, are practically the same for the percentages of methane and ethane

TABLE 1. HEATS OF COMBUSTION OF CONSTITUENTS OF FUELS AND OF STANDARD SUBSTANCES FOR CALIBRATING CALORIMETERS.

For combustion under constant pressure at 20 cent. to form gaseous CO_2 and SO_2 and liquid H_2O. Last column calculated for moisture saturated gas at 60 fahr. and under 30 inches of mercury total pressure.

			Heat of combustion (upper)				
Substance	Chemical formula	Molecular weight	kg. cal per gm.-mole	kg. cal. per gm.	1000 B.t.u. per lb.-mole	1000 B.t.u. per lb.	B.t.u. per cu. ft.
Carbon (sugar)	C	12.000	96.77	8.064	174.2	14.52	Solid
Sulphur	S	32.065	69.3	2.161	124.7	3.89	Solid
Hydrogen	H_2	2.0154	68.35	33.914	123.0	61.04	319.5
Hydrogen sulphide	H_2S	34.080	132.43	38.859	238.4	7.00	619.0
Carbon monoxide	CO	28.000	67.61	2.415	121.7	4.35	316.0
Saturated hydrocarbons							
Methane	CH_4	16.031	212.9	13.28	383.2	23.90	995.
Ethane	C_2H_6	30.046	368.4	12.26	663.1	22.07	1722..
Propane	C_3H_8	44.062	526.3	11.94	947.3	21.50	2460.
Butane	C_4H_{10}	58.077	683.4	11.77	1230.1	21.18	3194.
Pentane	C_5H_{12}	72.092	838.3	11.63	1508.9	20.93	3918.
Illuminants							
Ethylene	C_2H_4	28.031	332.0	11.84	597.6	21.32	1552.
Propylene	C_3H_6	42.046	496.8	11.82	894.2	21.27	2322.
Butylene	C_4H_8	56.062	647.2	11.54	1165.0	20.78	3025.
Pentylene	C_5H_{10}	70.077	803.6	11.47	1446.5	20.64	3756.
Acetylene	C_2H_2	26.015	312.0	11.99	561.6	21.59	1458.
Benzol	C_6H_6	78.046	787.2	10.09	1417.0	18.16	3680.
Toluol	C_7H_8	92.062	936.0	10.17	1684.8	18.30	4375.
Benzoic acid	$C_7H_6O_2$	122.05	771.2	6.319	1388.2	11.37	Solid
Salicylic acid	$C_7H_6O_3$	138.05	723.1	5.238	1301.6	9.43	Solid
Naphthalene	$C_{10}H_8$	128.06	1231.8	9.619	2217.2	17.31	Solid
Sugar Cane	$C_{12}H_{22}O_{11}$	342.17	1349.6	3.944	2429.3	7.10	Solid

found by the conventional method of analysis as for the actual percentages of saturated hydrocarbons present. A method of fuel gas analysis is often used in which the hydrogen is not determined separately by oxidation with copper oxide but is calculated with methane after combustion in oxygen. The hydrogen and methane so determined are equivalent to all the saturated hydrocarbons present.

As indicated by the preceding discussion, the composition of a fuel gas is usually given on the dry basis because the method of analysis does not give the amount of water vapor present. The latter is generally specified by saying that the gas is saturated with water vapor at a certain temperature and under a certain total pressure. A temperature of 60 fahr. and a total pressure of 30 inches of mercury (reduced to 32 fahr.) have been selected as standard by the American Gas Association. Corresponding to these conditions, there is present 0.0177 mole of water vapor per mole of dry gas in moisture saturated gas.

Calculation of Heating Value From the Chemical Analysis

The heating value of gaseous fuel can generally be calculated with a high degree of accuracy from its volumetric analysis and the heats of combustion of the components as given in Table I, if the proportion of illuminants is low. The heating value per cubic foot of gas given in the last column, is for moisture saturated gas at 60 fahr. and under a total pressure of 30 inches of mercury, the standard conditions adopted by the American Gas Association. It was calculated by dividing the heat of combustion per lb.-mole by 385.1 cu. ft., the volume of one lb.-mole of dry gas in moisture saturated gas under these conditions. For any other standard conditions, the heat of combustion per cubic foot can be found by dividing the heating value per lb.-mole by the volume of one lb.-mole under these conditions. For dry gas under 29.92 inches of mercury at 68 fahr. as specified in the A.S.M.E. Test Code for Stationary Steam Boilers, the volume of one lb.-mole is 385.3 cu. ft. The heating value of a gas under the standard conditions specified in the A.S.M.E. Boiler Test Code will thus be but slightly different from the heating value under the American Gas Association standard conditions.

For solid and liquid fuels, it has been proposed to calculate the heating value from the chemical analysis and the heats of combustion of carbon, hydrogen and sulphur. The following formula was first proposed for this purpose by Dulong, one of the early investigators of the heating values of fuels:

$$Q = 14500\ C + 61000\ (H - \frac{0}{8}) + 3900\ S$$

where C, H, S and O are the weight fractions of carbon, hydrogen, sulphur and oxygen in the fuel. Use of this formula assumes the oxygen present to be all combined with one-eighth of its weight of hydrogen to form water. The formula has sometimes been modified to indicate the oxygen to be combined with carbon to form carbon dioxide by subtracting three-eighths of the weight of oxygen 0 from the carbon C instead of one-eighth from the hydrogen H.

In applying the formula to coal, the heat of combustion of free sulphur 3900, has sometimes been replaced by the heat of combustion of iron pyrite, taken as 5250 B.t.u. per lb. of sulphur in the pyrite, because sulphur in coal mostly occurs in this form. (If the iron burnt to Fe O, the heat of combustion of the pyrite would be 4810 B.t.u. per lb. of sulphur; if to $Fe_2\ O_3$, the heat of combustion would be 5690 B.t.u. per lb. of surphur. The above value proposed by Somermeier is a mean of these two figures.) Some of the sulphur may be organic sulphur in combination with carbon and hydrogen, and in rare instances it may even occur as free sulphur. In weathered coal, the sulphur is mostly in the form of sulphate of iron, lime and alumina due to breaking down of iron pyrite, and in this form the sulphur has practically no heating value.

The heating value of carbon in Dulong's formula has been taken as 14500 B.t.u. per lb. The heating value of carbon, however, varies with the physical state of the particular sample tested, which is determined by the physical and chemical history of that sample. In the International Critical Tables, the particular form of graphitic carbon selected as standard has a heating value of 169,700 B.t.u. per lb.-mole, equivalent to 14,140 B.t.u. per lb. As this is considerably lower than the value heretofore employed in engineering calculations, the heat of combustion of sugar carbon has been given in Table I, and used in Dulong's formula.

The heats of combustion in Table I. have been calculated from data in the International Critical Tables with the exception of hydrogen, carbon monoxide and methane. These have been taken from more recent determinations at the U. S. Bureau of Standards.

The actual heating value of a fuel is often considerably different from that calculated by Dulong's formula, due to exothermic and endothermic reactions involved in breaking up the chemical compounds in the fuel. An exothermic reaction is one which gives out heat. Due to exothermic reactions in burning wood, the actual heat produced is considerably greater than that calculated by this formula. An endothermic reaction is one which absorbs heat. Most constituents of gaseous fuels absorb heat in being broken down into their elements, so that the application of Dulong's formula to gaseous fuels generally gives heating values which are too high. In coal, both exothermic and endothermic reactions probably occur, and if these do not balance, the actual heating value may be higher or lower than that calculated by Dulong's formula. The differences may be as high as 12 per cent with peat, 6 per cent with lignite, 4 per cent with sub-bituminous coal and 2 per cent with bituminous and anthracite coal.

Estimating Heating Values From Physical Properties of Fuels

Attempts have been made to relate the heating value of a fuel to properties of the fuel other than the chemical analysis, generally some physical property. For coal, the heating value has been found by Kent to be approximately related to the percentage of fixed carbon in moisture and ash free coal as indicated by the curve of Fig. 1, reproduced from Kent's book on "Steam Boiler Economy." For eastern and mid-western coals of the United States containing more than 60 per cent fixed carbon in moisture and ash free coal, Kent's curve probably represents the heating value within 2 or 3 per cent. For western sub-bituminous coals and for lignites, considerably larger differences occur.

For petroleum and its products, a close correspondence has been found between the heating value and the specific gravity as represented by the curves of Fig. 2 plotted from data in U. S. Bureau of Standards Miscellaneous Publications No. 97 entitled "Thermal Properties of Petroleum Products." The upper curve for the gross heating value is said to represent experimental values within one per cent based on oil free of sulphur, moisture and ash. It was calculated from the empirical relation

$$Q_V = 22{,}320 - 3780\ d^2$$

where d = specific gravity of petroleum at 60/60 fahr. and

Q_V = heating value in B.t.u. per lb. of sulphur, moisture and ash free oil at constant volume as determined by a bomb calorimeter.

The derivation of the formula for calculating the lower heating value under constant pressure from the upper heating value at constant volume will be explained later in this article. An empirical relation between the weight fraction H of hydrogen in the fuel oil and the specific gravity d of the latter was first selected, namely,

$$H = 0.26 - 0.15\ d$$

This relation is also shown graphically in Fig. 2. From the formula derived later, the lower heating value under constant pressure is

$$Q_{PL} = Q_V - 1080 \times 9\ (0.26 - 0.15\ d)$$

This expression is slightly different from the one given in the publication mentioned because there is an apparent error in the latter due to adding instead of subtracting the correction for conversion from constant volume to constant pressure combustion. If the fuel oil is not free of sulphur, moisture and ash, then the actual heating values are

$$Q'_V = Q_V\ (1-S-M-A) + 3900\ S \text{ and}$$

$$Q'_{PL} = Q_{PL}\ (1-S-M-A) + 3900\ S - 1110\ M$$

where S, M and A are the weight fractions of sulphur, moisture and ash respectively and 3900 B.t.u. per lb. is the heat of combustion of sulphur to sulphur dioxide.

Determination of Heating Value by Calorimeter

While the heating value of a solid or liquid fuel can be calculated approximately from the chemical analysis or estimated from some physical characteristics as above explained, the only accurate method of determining the heating value is by burning a small sample of the fuel with oxygen in a bomb immersed in a known weight of water and measuring the rise in temperature of the water. The water equivalent of the metal parts of such a bomb calorimeter is determined experimentally by burning a standard substance having a known heating value. Benzoic acid was selected as the standard substance for this purpose by the Third Conference of the International Union of Pure and Applied Chemistry which met at Lyons in 1922. Salicylic acid has been proposed as a secondary standard and naphthalene and cane sugar have been used with the heating values given in Table I.

For a gaseous fuel, it is preferable to determine the heating value experimentally rather than calculate it from the analysis if the gas contains an appreciable proportion of illuminants. The type

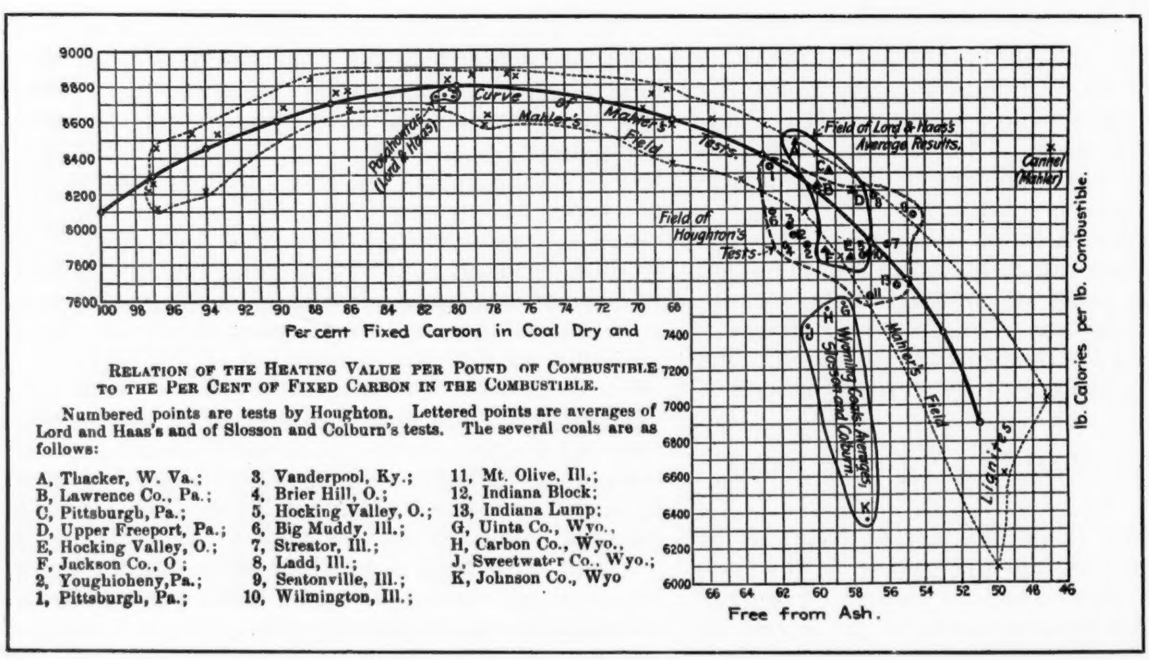

Figure 1
(Reprinted by permission from "Steam Boiler Economy" by Kent, published by John Wiley & Sons, Inc. This book is permanently out of print.)

of calorimeter usually used for this purpose is known as the flow type because the products of combustion of the fuel gas and air flow continuously through the calorimeter where they are cooled to the initial temperature of the gas and air by running water. The rate of flow and temperature rise of the water indicate the rate of heat absorption from the gas being burned, which is measured by means of a suitable meter. The temperature, barometric pressure and relative humidity of the atmospheric air are noted and any moisture condensed from the products of combustion in the calorimeter is measured. These data enable the heating value of the gas to be calculated for any desired standard conditions. As stated previously, the standard conditions of the American Gas Association are for the gas saturated with water vapor at 60 fahr. and under a total pressure of 30 inches of mercury. In the A. S. M. E. Test Code for Stationary Steam Boilers, the standard conditions for a fuel gas are stated to be dry gas at 68 fahr. and under 29.92 inches of mercury.

Factors Influencing Heating Value

The heating value of a fuel varies with a number of factors which are mentioned or implied when the heating value is given. Thus, for a solid fuel, the heating value is generally for unit weight of fuel. For a liquid fuel, unit weight is generally specified although the heating value per gallon is sometimes employed by reason of the fact that liquid fuels are generally sold by the gallon, or by the barrel of 42 gallons. Due to a considerable variation in density of liquid fuels with temperature, it is necessary to specify the temperature at which the volume of the fuel is measured. For gaseous fuels, the heating value is generally given per cubic foot of gas, and it is necessary to specify the temperature, pressure and humidity of the gas in order to make the heating value definite.

The heating value may be for the fuel as fired, often stated for solid and liquid fuels to be for the fuel "as received," referring to the samples as received in the laboratory for analysis. The determination is generally made, however, upon an "air dried" sample in case of coal and other solid fuels. The heating value may be reduced to "moisture free" fuel, commonly spoken of as dry coal, dry gas, etc., or it may be reduced to "moisture and ash free" fuel, often called combustible.

It is generally assumed that the heating value corresponds to the products of combustion being brought to the same temperature finally as that of the fuel and oxygen, or atmospheric air, initially. This temperature is usually said to be room temperature, but in scientific work it is necessary to be more specific because the heat of combustion varies with temperature by reason of differences between the heat capacities of the products after combustion and of the fuel and air before combination.

Combustion is generally assumed to take place with atmospheric air and may be at constant volume or under constant pressure. In the oxygen bomb calorimeter used to determine the heating value of solid and liquid fuels, combustion occurs at the constant volume of the bomb. In flow calorimeters used to determine the heating value of gaseous fuels, combustion occurs under the nearly constant pressure of the atmosphere. When a fuel is burned in an industrial furnace, combustion usually takes place under practically constant pressure. In an internal combustion engine, combustion may occur at nearly constant volume or under nearly constant pressure. There is a difference between the heating values at constant volume and under constant pressure due to the final volume of the products of combustion being different from that of the fuel and air initially when at the same temperature and pressure.

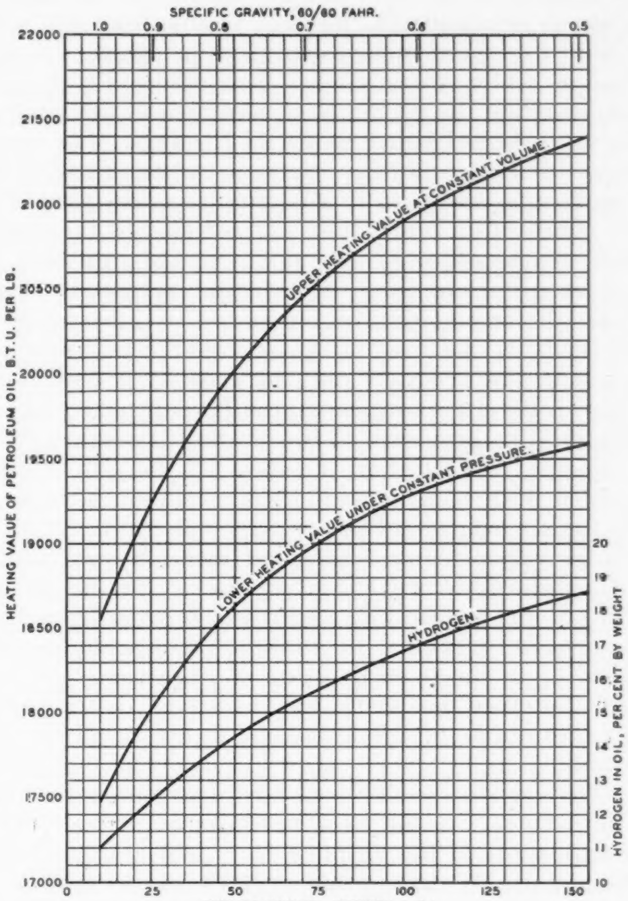

Fig. 2—Heating value of and hydrogen in petroleum oil.

When combustion takes place under constant pressure, the normal atmospheric pressure of 29.92 inches of mercury is generally taken as standard. For combustion in ordinary furnaces, no correction is necessary for the slight differences that may exist from normal atmospheric pressure. Heat balances for such furnaces are usually so made that it is also unnecessary to correct the heating value from room temperature to that at which combination of the fuel with oxygen actually occurs. In combustion calculations pertaining to internal combustion engines, however, allowances must be made for variations in heating value due to

both pressure and temperature if the details of the changes therein are to be investigated.

The state of the products of combustion is important as well as that of the fuel originally. Unless otherwise stated, it is assumed that the moisture formed from hydrogen in the fuel is condensed to liquid while the moisture originally present as such in the fuel is reduced to the same state as originally in the fuel. Thus, for solid and liquid fuels, the moisture originally present in the fuel as water is assumed to be condensed to liquid again when the products of combustion are cooled to the original temperature of the fuel. For gaseous fuels, the moisture present as water vapor in the fuel is assumed to so remain in the products of combustion when they are reduced to the original temperature of the gas. As the number of moles of products of combustion is usually less than the initial number of moles of air and gas burned, the amount of water vapor remaining as such in the products may be greater or less than that in the air and gas originally, depending upon the relative humidity of the air and the amount of moisture contained in the gas. If the gas is saturated with water vapor, then a relative humidity of the air over about 80 per cent will result in more water vapor being condensed when the products of combustion are cooled to the initial temperature of the gas and air than was formed from the hydrogen burned. In making flow calorimeter tests upon the heating value of a gas, corrections are therefore necessary for variations in the relative humidity of the atmospheric air supplied for combustion.

The carbon dioxide formed from combustion of the carbon and the sulphur dioxide formed from combustion of the sulphur in a fuel are assumed to remain in gaseous form. These assumptions correspond to what actually occurs during the determination of the heating value of gaseous fuels. But when the heating values of solid and liquid fuels are determined in the bomb calorimeter, the sulphur dioxide formed is oxidized to sulphur trioxide and combined with water to form an aqueous solution of sulphuric acid and there is some formation of nitric acid. Corrections are usually made for the heat evolved in producing these acid solutions.

Lower Heating Value

In certain calculations involving the heating value of a fuel, it has become customary to use a lower or net heating value corresponding to the water vapor remaining as vapor at room temperature instead of being condensed. The lower heating value is calculated from the upper, gross or total, heating value (as it is variously called) by subtracting the "latent heat" of the water vapor formed from the hydrogen in the fuel and originally present as water in solid and liquid fuels. Since room temperature is actually below the dew point of products of combustion, an apparent rather than a real value of the latent heat must be used. For cooling under normal atmospheric pressure, the value of this apparent latent heat was shown in the article on the "Humidity of Gaseous Mixtures" to be about 1050 B.t.u. per lb of moisture for a final temperature of 70 fahr, and abut 1045 B.t.u. per lb. of moisture for a final temperature of 60 fahr. The equivalent values per lb.-mole of moisture are 18,900 B.t.u. at 70 fahr. and 18,800 B. t.u. at 60 fahr.

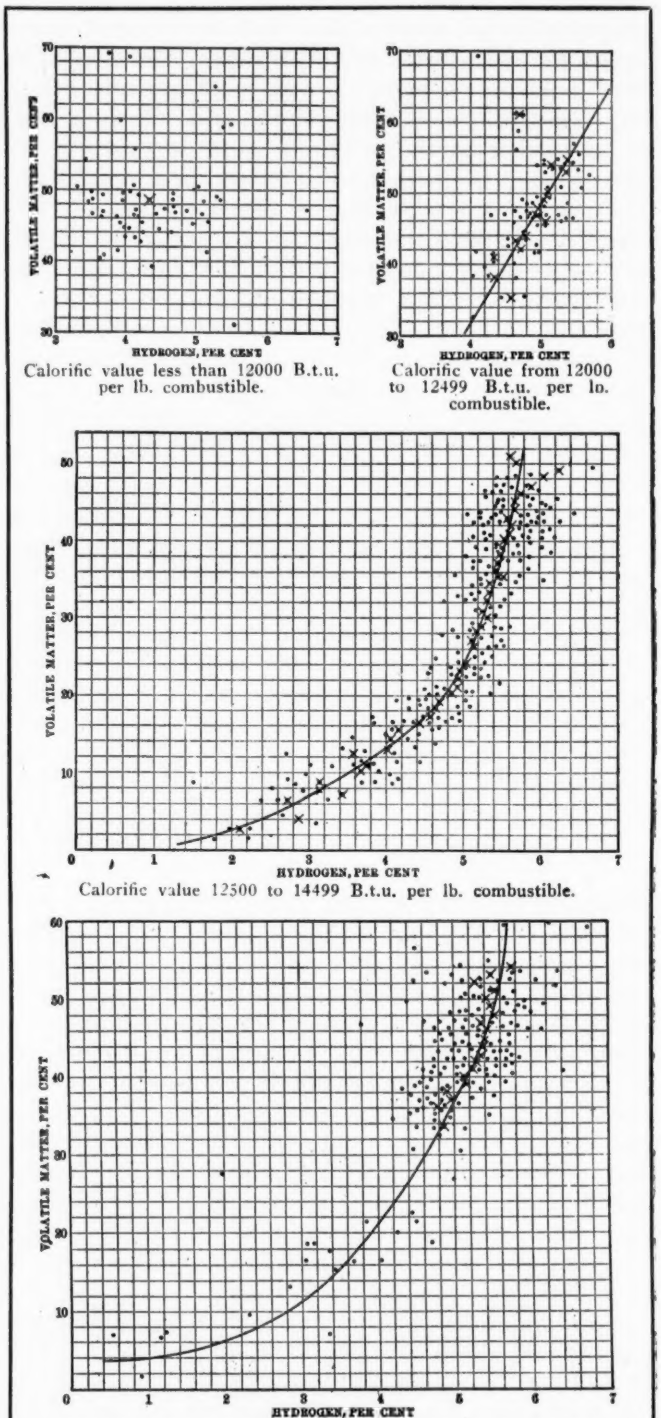

Fig. 3—Relations between hydrogen and volatile matter in moisture and ash free coals from U. S. Bureau of Mines Technical Paper 197.

The lower heating value for the combustion of a gaseous fuel under normal atmospheric pressure is found by subtracting from the upper heating value determined in a flow calorimeter, the above apparent latent heat of the water vapor formed

from the hydrogen in the gaseous fuel. The lower heating value for the combustion of a solid or a liquid fuel under normal atmospheric pressure may be found from the upper heating value determined in a bomb calorimeter, but the upper heating value should first be corrected to constant pressure combustion because in the bomb calorimeter combustion occurs at constant volume instead of under constant pressure as in the flow type calorimeter used for gaseous fuels.

The correction from combustion at constant volume to combustion under constant pressure is based on the fact that the number of moles of products of combustion of a solid or a liquid fuel is greater than the number of moles of air supplied for combustion due to the moles of oxygen, nitrogen and moisture added to the products from the fuel and to the moles of H_2O formed during combustion being twice the moles of O_2 entering into combustion with the hydrogen in the fuel. The sulphur and carbon of the fuel enter into combination with the oxygen of the air without any change in the number of molecules of the products of combustion as compared with the air supplied for combustion. For each mole that the products of combustion exceed the air supplied for combustion, the heat of combustion under constant pressure is less than the heat of combustion at constant volume by 385.3 x 144 x 14.696/778.6 = 1047 B.t.u. at 68 fahr. since the volume of one lb.-mole at this temperature is 385.3 cu. ft. under one atmosphere pressure. In this computation, the volume of the solid or liquid fuel need not be considered because it is negligible in comparison with the volume of the air supplied for combustion.

If Q_v denote the heat of combustion at constant volume of a solid or liquid fuel as determined in a bomb calorimeter, then the heat of combustion under constant pressure

$$Q_P = Q_v - 1047\left(\frac{H}{4} + \frac{O}{32} + \frac{N}{28} + \frac{M}{18}\right)$$

$$= Q_V - 262\,H - 33\,O - 37\,N - 58\,M$$

where H, O, N and M are the weight fractions of hydrogen, oxygen, nitrogen and moisture in the fuel. If we substitute for H, the weight of water vapor formed from the hydrogen in the fuel, namely, 9 H, we have

$$Q_P = Q_V - 29 \times 9\,H - 33\,O - 37\,N - 58\,M$$

With the amounts of oxygen and nitrogen usually encountered in solid and liquid fuels, the terms involving O and N may be neglected.

The low heating value at 68 or 70 fahr. of a solid or liquid fuel for combustion under constant pressure, is then given by

$$Q_{PL} = Q_P - 1050 \times 9\,H - 1050 \times M$$
$$= Q_V - 1080 \times 9\,H - 1110 \times M.$$

The curves of Fig. 3 are included for reference in determining the percentage of hydrogen from the percentage of volatile matter in American coals in order to calculate the lower heating value of coal from the upper heating value when the ultimate analysis of the coal is not available.

References

The publications of the U. S. Bureau of Mines and of the U. S. Bureau of Standards are particularly valuable for reference upon the subject of this article. For instance, U. S. Bureau of Mines Technical Paper 76 discusses very thoroughly the sampling and analysis of coal and Technical Paper 197 shows the approximate relation between the percentage of volatile matter and the hydrogen content of American coals. U. S. Bureau of Mines Technical Paper 323 A contains the United States Government Specifications for liquid fuels and methods for testing them. U. S. Bureau of Standards Miscellaneous Publications No. 97 contains the empirical relation found between the heating value and the specific gravity of petroleum fuels and other thermal data on petroleum products. U. S. Bureau of Standards Scientific Paper 230 contains a scientific discussion on the bomb calorimeter. U. S. Bureau of Miles Bulletin 42 describes the analysis of fuel gases. U. S. Bureau of Standards Technologic Paper No. 36 and Circular No. 48 describe the determination of the heating value of gaseous fuels. Two publications of the Engineering Experiment Station of the University of Illinois are of interest, namely, circular No. 12 on the analysis of fuel gas and Bulletin No. 37 on unit coal and the composition of coal ash. Standard methods for testing coal have been issued by the American Society for Testing Materials. Pennsylvania State College Bulletin No. 14 is also of interest as describing an empirical method developed by J. P. Calderwood for calculating the ultimate analysis of coal from its proximate analysis.

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Heat Cycles and Relative Efficiencies

(Continued from page 23)

about one-half the minimum amount of water required. The volume of 6.25 lb., of mercury vapor at 120 lb. abs. is 4.6 times the volume of one pound of water vapor at 600 lb. pressure. These considerations indicate the necessity of rather liberal cross-sectional areas of the paths of circulation.

Scientifically, the problems involved do not appear insurmountable. The design of a wall having low maintenance and a high degree of reliability at an economic cost, however, would appear to be a difficult problem which is likely to be solved only by a period of careful development and experience.

The subject of "cost" is not touched upon in this article. The article, therefore, can be regarded as only a beginning of an economic study. Information on the subject of cost is at the present writing, so inadequate that generalization is not justified. During development, economic studies to be profitable must be confined to specific cases on which full information is obtainable or may be computed. Likewise, and for the same reason the subjects, "maintenance," "reliability" and "availability" have been avoided.

Pulverized Fuel Firing Methods

A Discussion of the Design and Arrangement of Various Types of Burners

By GEORGE W. CLENDON
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New York

The author of this article has had an unusually long and diversified experience in the development of pulverized fuel equipment and firing methods. His work in this field dates back to the first applications of pulverized fuel firing to locomotives and to stationary steam plants. His experience has included operation of plants in all parts of the United States, using practically every kind of American coal, and has also extended to field work in South America and in the Orient . . . His comments and conclusions on the various present-day types of pulverized fuel burners and methods of firing are, therefore, of more than passing interest, and merit the careful consideration of engineers who are designing or operating pulverized fuel fired plants. . . . The conclusions presented in this article are based on the premise that with pulverized fuel the best results are secured by means of turbulent combustion. In the author's opinion, the simplest and most logical method of adapting turbulent combustion to boiler furnaces is by means of corner-firing in which simple burners are located in each of the four corners of the furnace so as to introduce the coal-and-air mixture into a swirling, cyclone of gases which fills the entire furnace and sweeps the water-cooled furnace walls, thus effecting a high rate of heat absorption.

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THE factors essential to the successful burning of pulverized fuel are time, temperature and turbulence. The fuel and air should so enter the furnace as to give the longest possible time for combustion of the coal particles. By increasing turbulence and temperature, time can be decreased. Hence, with intense turbulence and the use of preheated combustion air, which characterize modern practice, the rate of heat liberation per cubic foot of furnace volume is substantially increased.

Intense turbulence of combustion is generally recognized as the ideal condition for pulverized fuel burning. Various methods have been developed for securing this intimate and rapid mixing of fuel and air but certain of these methods approach the desired turbulent action only at the sacrifice of operating simplicity and reliability.

Many of the difficulties encountered in the burning of pulverized coal have been due to an inadequate appreciation of basic fundamentals and to the erroneous idea that burner changes and adjustments can compensate for inherent errors in furnace design and burner application.

Almost every engineer who becomes interested in pulverized fuel feels the urge to design a burner, and, when combustion conditions are unsatisfactory, the operating engineer's first inclination is to go to work on the burner.

There is a prevailing idea that the fuel and air must be thoroughly mixed in the burner. This theory could perhaps be successfully applied in practice were it not for the fact that at low ratings, when the velocity of the mixture may be lower than the velocity of flame propagation, combustion is likely to occur within the burner itself, ofttimes resulting in serious damage to the burner structure. Furthermore, no matter how thoroughly the fuel and air are mixed in the burner, they do not remain as a uniform mixture, and in order to prevent back-firing, it is necessary to surround the mixture with a secondary supply of air before it is blown into the furnace.

In an all water-cooled furnace, it is difficult to maintain stable ignition with the so-called turbulent or mixing burners when operated at low ratings, because of the manner in which the fuel-and-

air mixture travels away from the burner when its velocity is kept sufficiently high to prevent backfiring.

It is now generally accepted that modern furnace design, especially for large units, demands the elimination of refractories. Yet practically all of the mixing or turbulent burners require refractory material around the burner in order to assure stable ignition at low ratings. When the walls in which the burners are installed are water-cooled, it is necessary to cover the water tubes with some form of refractory or block so that the temperature at the burner mouth will be sufficiently high to maintain ignition. Furthermore, where this type of burner is installed in a water wall, difficulties are encountered in providing openings for the burners since the tubes must be bent around the burners, thus adding complications and increasing the cost of construction. This difficulty is illustrated in Fig. 3.

The design of most turbulent burners is complicated by the various adjustable features and several weeks of experimenting and field adjustment are generally required before satisfactory operation is obtained. Changes in the fuel used may necessitate a repetition of this entire procedure. From a practical operating standpoint, the design of burners should be so simple that an operator of average skill would have no difficulty with them, but unfortunately many turbulent type burners are so complex in design and adjustment that they can be operated successfully only by experts. Frequently the cost of the field engineering work required to adapt such burners to the fuel and load requirements of a particular installation exceeds the cost of burner manufacture.

Fig. 1 shows a section through a furnace fired with turbulent burners and Fig. 2 is a plan view of the same furnace. With such an arrangement, the flame is long, it fills only about 60 per cent of the furnace and impinges upon the boiler tubes before combustion is complete, thus causing excessive slagging on the lower boiler tubes and rear furnace wall.

The particles of fuel on the upper side of the flame travel a relatively short distance to the boiler tubes where they are cooled below the ignition temperature and are not thoroughly burned, thus adding greatly to the carbon loss in the flue ash. While this type and arrangement of burner give much better combustion results with high volatile coal than with low volatile coal, the use of high volatile coals leads to excessive burner maintenance since with such coals there is a tendency for the flame to travel back into the burner.

Fig. 4 shows a section of a furnace fired with a flat burner which extends across the furnace front. With this form of burner, the maintenance is not likely to be as high as with the burner arrangement shown in Figs. 1 and 2, but the combustion results are substantially the same.

From this consideration of turbulent or mixing burners, it is evident that they have serious limitations in meeting operating requirements for a wide range of fuel and boiler ratings. Such conditions of operation can, however, be met satisfactorily by burners of relatively simple design so located as to produce the desired mixing of fuel and air within the furnace.

The vertically-fired furnace, shown in Fig. 5, represents a simple form of furnace design and burner application. This is one of the oldest and

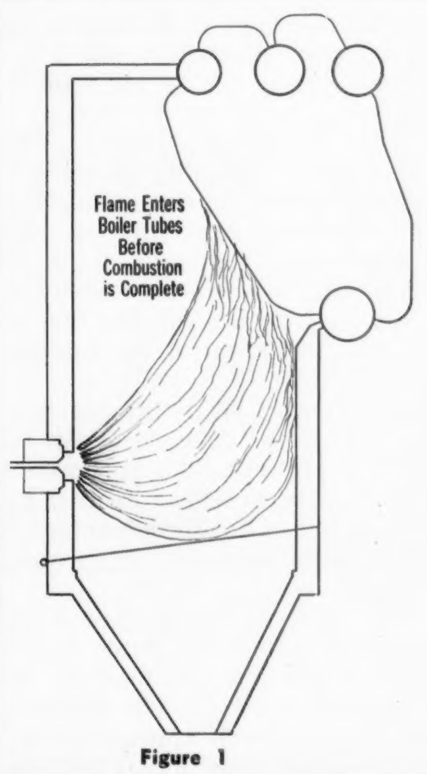

Figure 1

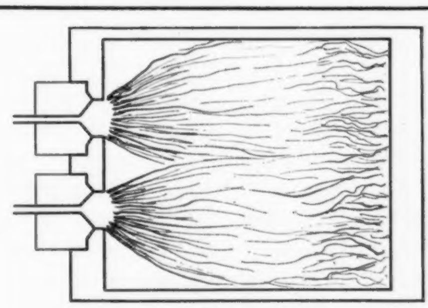

Figure 2

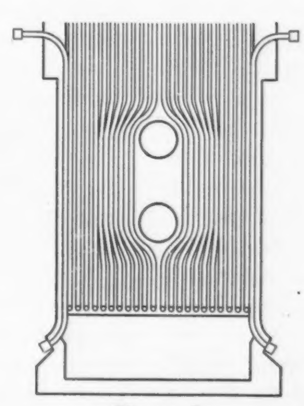

Figure 3

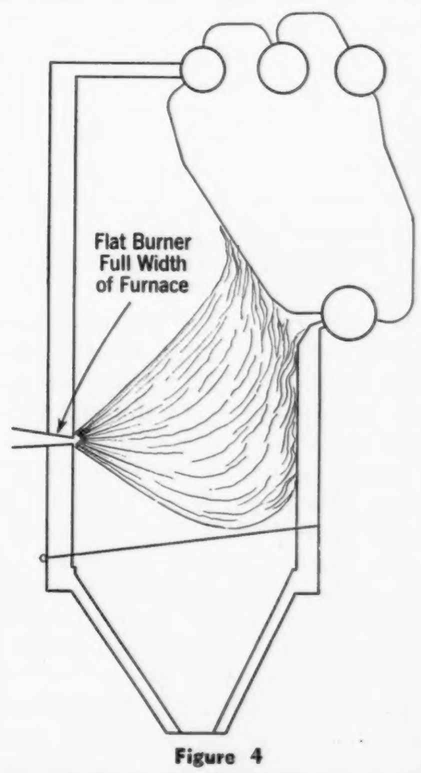

Figure 4

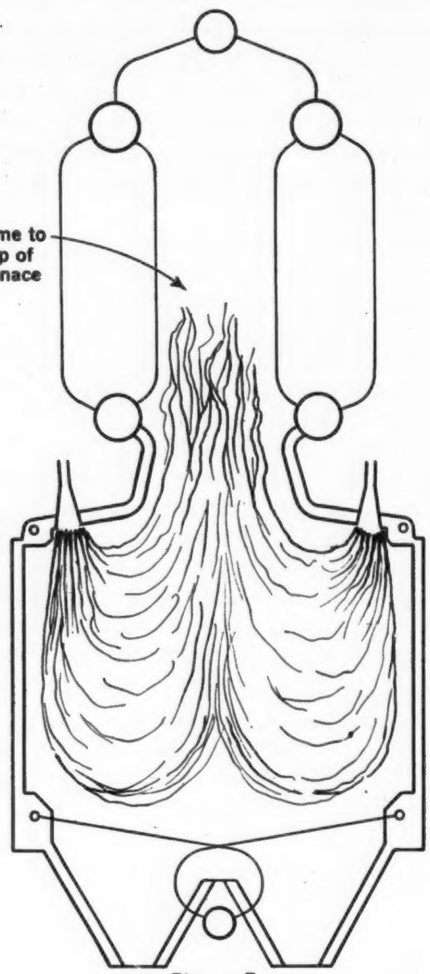

Figure 5

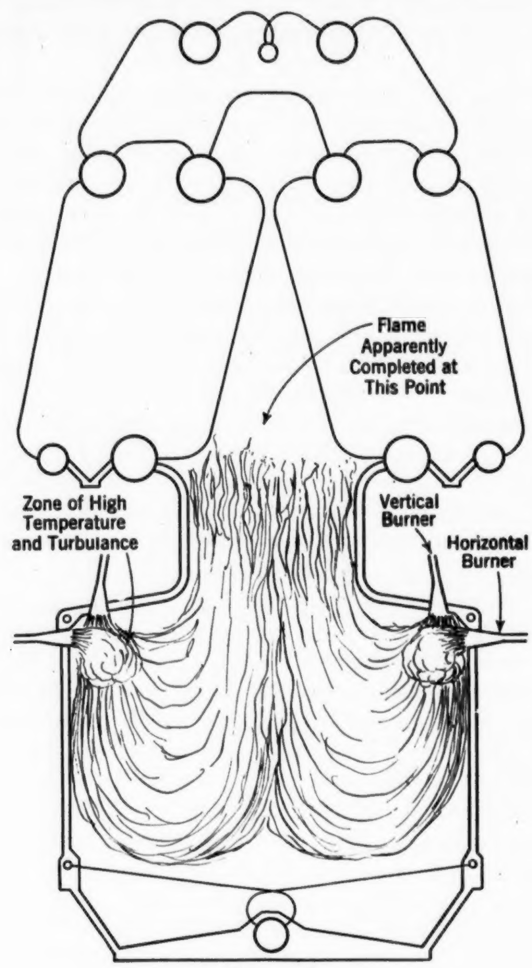

Figure 6

perhaps the most widely used of all the methods of firing pulverized fuel. It has been used successfully for burning a wider range of fuels than any other method, varying from anthracite culm, with 4 per cent volatile and 40 per cent ash, to high volatile lignites. For refractory furnaces, this form of firing has no equal, and it is also widely used in furnaces of practically 100 per cent water-cooled construction. The flame travel is in the form of a U, the radiant heat from the up-travel side of the flame igniting the fuel at the burners and insuring stable ignition at all ratings and with all grades of coal.

Many forms of turbulent burners have been applied to vertical-firing, but the simple, non-mixing type of burner has always proved preferable; in fact, practically all of the turbulent burners so applied have been removed.

The principal objection to the vertical method of firing, especially when used in water-cooled furnaces, is that the soft, long flame requires considerable furnace depth and the entire distance of flame travel for complete combustion. Since the permissible rates of heat liberation are relatively low, furnace volumes are correspondingly large with this method of firing.

A vertically-fired furnace with horizontal auxiliary burners in the front wall is shown in Fig. 6. The flame streams from the vertical and horizontal burners impinge on each other, causing pronounced turbulence with high temperatures close to the burners and a short, intense flame. Such conditions insure stable ignition at all ratings and permit the use of a completely water-cooled furnace. Although the temperature is high in the turbulent zone, the temperature at the bottom of the furnace is comparatively low, thereby eliminating much of the slagging difficulty experienced with most of the other forms of firing. This type of furnace (Fig. 6) has been successfully operated at rates of heat liberation up to 40,000 B.t.u. per cubic foot of furnace volume, a result that would be impossible were it not for the fact that this arrangement permits the utilization of the full volume of the furnace.

In vertically-fired furnaces, all of the fuel may be fired from one side of the furnace or, in the case of large units, from opposite sides as shown in Fig. 5. Both methods give excellent results, but the double-firing arrangement has the advantage of providing additional turbulence with consequent shortening of the flame.

A corner-fired furnace is shown in Figs. 7 and 8. With this method of firing, the flame stream from each of the four corners impinges on the stream from the adjacent corner. The resulting flame travel is almost cyclonic in appearance and effect, causing intense turbulence and high tem-

peratures, with stable ignition close to the burners. The flame is short, clear and intense, and the heat liberation per cubic foot of furnace volume is exceedingly high. The combustion flame is practically completed within that portion of the furnace extending from the burners to a point about three feet above. Plain burners of the simplest possible design are used with this form of firing.

As a consequence of the turbulence and the complete filling of the bottom zone of the furnace with a uniform and intense flame, the rate of heat absorption by the water walls is high and the temperature at the top of the corner-fired furnace, shown in Fig. 7, is 200 deg. lower than the temperature at the corresponding point in a vertically-fired furnace installed in the same plant, which is of equal dimensions and which burns the same fuel. At this plant there was recently placed in operation a second corner-fired furnace in which the turbulence is more severe than in the furnace just described. As a result of the short, intense flame at the bottom of this latter furnace and the higher absorption of heat by the water-cooled walls, the temperature at the top of the furnace is nearly 500 deg. lower than in the vertically-fired furnace installed at this plant.

Corner-firing has been successfully used with pulverized coal, fuel oil and blast furnace gas, and,

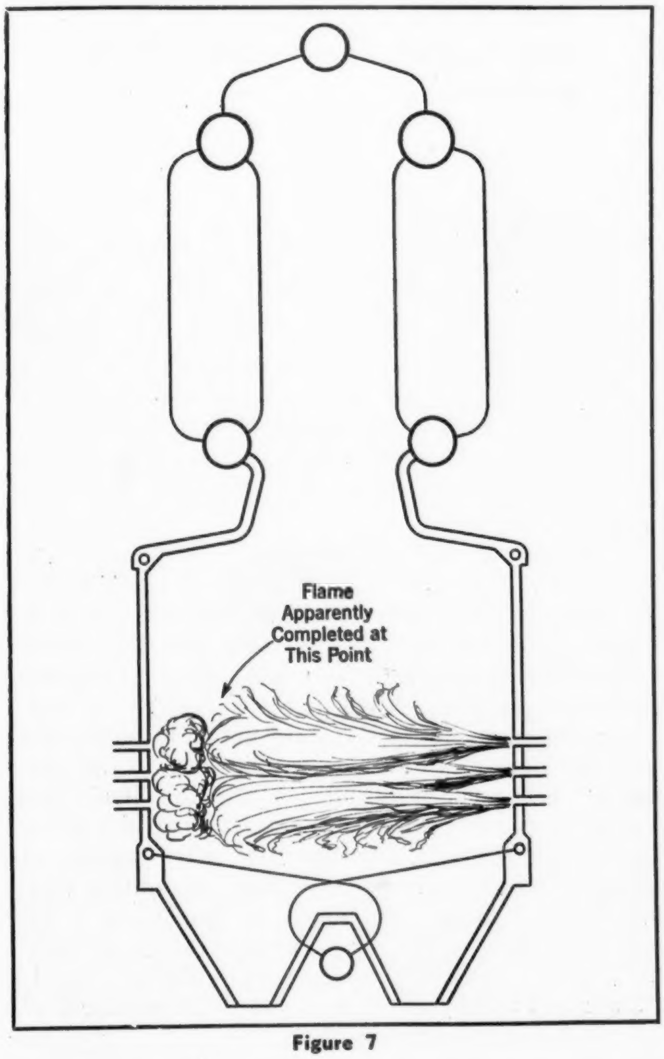

Figure 7

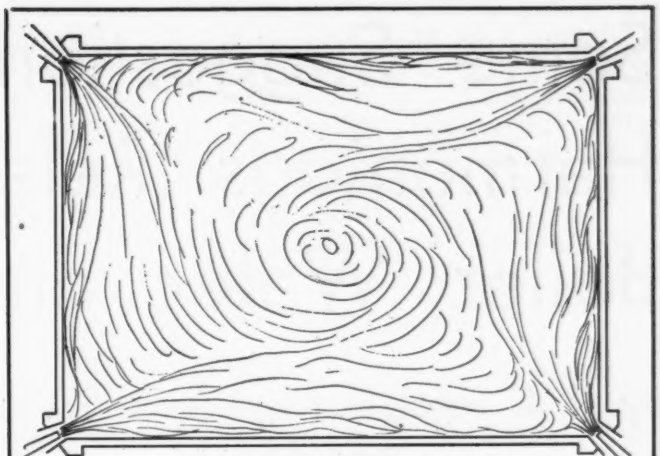

Figure 8

judging from the short flame obtained with the latter fuel, it should also prove satisfactory with natural gas.

Due to the intense turbulence and high temperatures secured in corner-fired furnaces, no form of refractory or block covering on the water wall tubes would last more than a few days. Thus a water-cooled furnace with bare tubes is not only desirable, but absolutely necessary with this form of firing.

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Considerations in the Design of the Small Boiler Plant

(Continued from page 28)

tains six 600 hp. Badenhausen boilers, each fired by a six-retort Westinghouse underfeed stoker and operating at 200 lb. pressure and 100 deg. superheat. Ash is discharged from large hoppers under the boiler furnaces into an ash car which conveys it to a skip hoist and an overhead tank where it is stored and from which it is later distributed into trucks or railroad cars. The plant is an efficient one and has given excellent service but if it were projected today there is but little doubt that the units would consist of but three or at the most four instead of six; they would probably be fired with powdered coal and have an entirely different furnace design. The ash disposal would fit well into the Hydrojet system since an enormous amount of fill is required around the mill and this would be an ideal method for that purpose.

Less than a decade has passed since these boiler units were installed but a comparison with the larger units now in service well illustrates one of the opening remarks of this article, "it is in the boiler house that the greatest changes have come about in the sense of departure from previously accepted practice."

Some Suggestions Regarding Harmonious Relationship between Boiler Water and Metal*

By R. E. HALL, Hall Laboratories, Inc., Pittsburgh, Pa.

Dr. Hall discusses the various types of boiler metal corrosion, the conditions that cause or contribute to their occurrence, and methods of prevention, both chemical and mechanical. He presents the circumstances of several cases of corrosion and the means used in each case to correct the condition. Maintenance of the correct pH value, which the author describes as the rate-factor in corrosion, and removal of dissolved oxygen, the quantity-factor, are given as the two principal requisites to the solution of corrosion difficulties.

CORROSION manifests itself in two distinctive forms: (a) General corrosion, comprising pitting, grooving, and any general attrition, accelerated among other things by the stresses to which the metal is subjected, but not necessarily and not usually primarily dependent thereon; and (b) Boiler metal cracking, comprising transcrystalline and intercrystalline failures, sometimes designated respectively, corrosion fatigue, and caustic embrittlement, and resulting primarily from simultaneity of corrosion and stress, and especially cyclic stress.

The prevention of corrosion necessitates recourse to both chemical and mechanical means for maintaining requisite conditions in the system.

General Corrosion and Its Prevention

Iron dissolves in water when the pH value of the water is less than about 9.6[1]. The amount of iron that dissolves in pure water is not large, nevertheless the dissolution is certain. Thus if a boiler is fed with pure water it will continue to dissolve the metal, whether from the pre-boiler equipment or from the boiler itself, until such time as the pH value of 9.6 is attained. The conclusion is unavoidable that pure water does not represent the best relationship between metal and water, and that the pH value of the water should be made by artificial means to attain the value of 9.6 and thus avoid this slight dissolution of the metal. The most convenient source of hydroxyl radical to so raise the pH value is caustic soda. Careful chemical control for adjustment of pH value is essential, since this is primarily the rate-factor in dissolution of the metal, and hence corrosion.

The other factor in elimination of corrosion consists in removal of dissolved oxygen from the water to the greatest extent possible. As iron dissolves in water it forms ferrous hydroxide and hydrogen. As stated above, in pure water the reaction does not proceed to any great extent, but when oxygen is present it combines with the hydrogen to form water; and with the ferrous hydroxide to form ferric hydroxide or oxide, which is the red substance characterizing iron rust; or to form magnetic oxide or ferrous oxide, which is black, and more characteristic of corrosion at high temperature. Thus the oxygen removes both the hydrogen and the ferrous iron from the water, and because of this, further dissolution of the metal occurs. The oxygen therefore is the quantity factor in the corrosion process, because it is the factor causing a sustained high rate of solvent action of water on the metal.

To what extent must oxygen be removed from the water? The answer is definite. So long as the pH value of the water is above 9.6, and the oxygen remains dissolved in the water, no particularly deleterious corrosive action will occur. Against a heating surface, however, the solubility of oxygen in water becomes less, and hence bubbles may form and attach themselves at random to the surfaces. Wherever a bubble so attaches itself, the whole effect of maintaining alkalinity in the water has been destroyed, because that little portion of metal underneath the bubble is not in contact with the alkaline water, and hence at this point a pit starts and grows. Therefore the deaeration must be sufficient so that with increasing temperature, atattachment of any bubbles of gas to the surfaces of the metal cannot occur.

* Presented before Metropolitan Section, A. S. M. E., February 24, 1931.

[1] Wherever a pH value of 9.6 is referred to in this discussion, it will be understood to represent the value determined on a sample drawn without flashing, and cooled to ordinary room temperature.

Theoretically the open, vented feed water heater, operating at 212 deg. fahr., should give zero oxygen water. Because of the time-factor involved in giving the oxygen molecules access to the surfaces where the oxygen partial pressure is maintained at practically zero by the excess steam used for venting, this is never the case, and the residual dissolved oxygen amounts to perhaps 0.2-0.3 ml. per liter. In case the temperature of the heater is raised to 230 deg. fahr. or thereabouts, better removal of oxygen is obtained, and I believe the common practice is to guarantee either the deaerator working at lower temperatures under reduced pressure, or the deaerating heater working at 230 deg. fahr., to about 0.025 ml. per liter of oxygen. These processes are mechanical, and will give water sufficiently free of oxygen so that for all practical purposes any corrosion therefrom, ascribable to oxygen, is at a standstill. However, if it is desired to remove the oxygen more completely, then the method of chemically fixing it must be resorted to. The materials used for thus fixing the oxygen may be iron scrap, as proposed some years ago with the "Deactivator," or ferrous hydroxide, which readily combines with oxygen, or other chemical material which will combine with any remaining oxygen and thus remove it.

We now turn to some cases of general corrosion:

Case A.—In this case conditions may be represented diagrammatically as follows:

Scale and Severe Corrosion.

Zeolite Softener | — Deaerating Heater | — High Pressure Heater | — 4-drum bent tube boiler

↑

$O_2 = 0.1 — 0.3$ ml/liter

Inexact alkalinity control

The bicarbonate water after passing the zeolite softener was given an inexact pH value control by the addition of some caustic soda and trisodium phosphate at the point indicated. Oxygen content in the effluent water from the deaerating heater varied from 0.1 to 0.3 ml. per liter. Very severe corrosion occurred in the boiler, affecting the surfaces of both tubes and drums. Formation of considerable scale was also a complicating factor in this case.

The following outline shows what has been done to operate with no boiler scale and no corrosion:

No Scale; No Corrosion.

Zeolite Softener | — Deaerating Heater | — High Pressure Heater | — 4-drum bent tube boiler

↑

$O_2 = 0.02 — 0.04$ ml/liter

Exact alkalinity control

Alkali Reducing Phosphate. Sulphate and Alkalinity Control

Deaeration in the deaerating heater has been improved so that the effluent water now contains from 0.02 to 0.04 ml. per liter of dissolved oxygen. Exact alkalinity control has been established on the water flowing from the softener. Since accumulation of the alkalinity necessary here would result in too high alkalinity in the boiler water, the phosphate, which is requisite for preventing scale formation, is added in the alkali-reducing form of metaphosphate. With the combination as outlined, scale and corrosion have disappeared. Because the boiler water alkalinity also is under exact control and maintained low, there is no difficulty in holding the required sulphate—alkalinity ratios.

Case B: The diagram illustrates the arrangement of equipment in this case.

Corrosion; Heavy Blowdown

Continuous Hot Process Lime-Soda | — Filter — | 3-drum bent tube boiler { Feed water inlet to bottom drum. Blowdown — upper rear drum.

↑

Oxygen: 0.3 ml/liter or less

Alkali Reducing Phosphate

The corrosion in the bottom drum of this 3-drum bent tube boiler represented the worst condition, but corrosion and pitting were occurring throughout the boiler, and especially in the cross-over water tubes between the front and rear drum, and in the tubes connecting the bottom drum and the upper front drum. In one boiler there was also considerable corrosion of the front drum itself.

The alkalinity factor in the feed water is taken care of by the process of softening, since the effluent water from the hot process lime-soda softener has a pH value as high as required. The question in this case therefore was whether the oxygen would have to be reduced below the 0.3 ml. per liter which was maximum as conditions stood. The corrosion in the boiler was doubtless occurring because as this feed water reached the boiler and its temperature was raised, bubbles of oxygen were disengaged from the water, attached themselves to the surfaces at various places, and underneath these bubbles the surface of the metal was unprotected by the proper pH value in the water.

If this amount of oxygen in the steam, namely 0.3 ml. per liter, would be the cause of any corrosion in steam lines and equipment, then the preferable answer would lie in the installation of a deaerating heater to change the figure 0.3 to 0.03 or 0.02. An alternative would be chemical fixation. On the other hand, if this amount of oxygen in the steam had not been doing damage, and for the conditions as they exist at present would not do damage, then this outlay of money could be avoided.

The following diagram shows what was done:

No Corrosion; Blowdown Largely Reduced.

Continuous Hot Process Lime-Soda | — Filter — | 3-drum bent tube boiler { Feed water inlet into trough in upper rear drum. Blowdown—upper front drum.

↑

Oxygen: 0.3 ml/liter or less

Alkali-Reducing Phosphate

The feed water inlet, which had been in the bot-

tom drum was changed to a trough in the upper rear drum. Thus water entering the boiler and spilling over the edge of the trough was brought in contact in thin layers with the live steam, and splashed on the top layers of the boiler water so that during all of this period the path of a molecule of oxygen to a surface at which it could escape was short. This one change has settled the corrosion problem, as these boilers are and have been for several months totally free of any corrosion.

The change of continuous blowdown from upper rear to upper front drum was very advantageous, in that it brought the inlet to the point of highest concentration in the boiler water, and hence made each unit of blowdown water most effective in diminishing the concentration thereof. With crystalline deposits in the boiler water such as calcium carbonate, the blowdown must be located near the bottom of the boiler, since the crystals and the flakes of scale that form along with them are too heavy to be homogeneously distributed in the boiler water. In the use of combination phosphate treatment, exactly controlled, as above, there are no flakes of scale or heavy crystals, and the insoluble material that develops is adapted to homogeneous distribution though the boiler water. Therefore, the blowdown for concentration control can be located at the point of highest concentration of dissolved solids in the boiler water, because that very point will represent as well highest concentration of the sludge in suspension. Of course, an outlet at a low point is necessary for the occasional drainage of the boiler.

Case C: The severe dry conditions of the past summer were responsible for the occurrence of this case. For approximately four years these boilers had been in splendid condition, with no sign of corrosion. They were inspected about the middle of July and no evidence of corrosion was apparent; sixty days later severe corrosion was evident in the boiler drum and in the rear header. The layout of equipment is given in the diagram.

Corrosion.

Intermittent Lime-Soda — Vented Direct Contact Heater — Cross Drum Boiler {Feed water inlet usual submerged pipe. Blowdown from mud drum.

↑ Alkali-Reducing Phosphate

This plant is on the Monongahela River, and during the period of drought the sulphate in the feed water reached over 600 p.p.m., whereas now with the wet weather we have had it has fallen to considerably below 100 p.p.m. In consequence of the severe conditions there had been increase in blowdown, and some drop in temperature at the heater. The remarkable thing to my mind however is that in sixty days this severe condition of corrosion should develop. Alkalinity conditions in the feed water and boiler water were held correctly at all times, therefore the trouble must be dissolved oxygen. We believe that the dissolved oxygen gaining entrance when the temperature of the heater was reduced because of excessive blowdown, and being formed into bubbles, partly at points near the feed water inlet as the temperature rose, and partly in its flow along the rear header, caused this corrosion because under the surfaces of bubbles the alkalinity of the water cannot be protective. Further, there is no question in our minds that the blowdown was so excessive because the feed water before having opportunity to become homogeneously mixed with the rest of the boiler water passed down the rear header and thence into the blowdown, which therefore was much less effective than it should be.

On the basis of this analysis we made changes as represented in the following diagram:

No Corrosion; Reduced Blowdown.

Intermittent Lime-Soda | Vented Direct Contact Heater | — Cross Drum Boiler {Feed water enters above boiler water level from trough. Blowdown from steam drum between drum wall and steam baffle

↑ Live Steam and Temperature Control ↑ Alkali-Reducing Phosphate

Continuity of maintenance of temperature in the heater was assured by bleeding live steam thereto, with temperature control. As a second measure the feed water inlet was changed to a trough above the water level in the drum, so that a short path of escape would be given to oxygen molecules as the temperature of the incoming feed water was raised to that of the boiler. Third, the blowdown was changed from the mud drum to a point between the vertical baffle, against which the steam from the cross-circulating tubes impinges, and the drum. Tests on boiler water samples taken simultaneously from the main drum and from the newly-installed continuous blowdown, show that the latter is 25 per cent more concentrated than the former. An inspection within the last few days shows that all corrosion has ceased.

Boiler-Metal Cracking

We turn now to the form of corrosion that manifests itself in boiler metal cracking. The failures that occur under this general heading have in common that they result from simultaneity of corrosion and stress, especially cyclic stress.

By use of Fig. 1 we may define the different types of cracking. Point B of the diagram, a boundary point between the *region of acid attack* and the *region of protection,* corresponds to a pH value of approximately 9.6 Point C, a boundary between the *region of protection* and the *region of caustic attack,* corresponds to a caustic concentration of some 8 or 10 per cent. As operating pressure, or in other words, temperature, increases, the *region of protection* will be confined to narrower limits because chemical activity increases with increasing temperature.

Region of Acid Attack: If the pH value of a boiler water is less than 9.6, then that boiler water lies in the *region of acid attack.* This attack may be manifested in the form of general corrosion, heretofore discussed, or more rarely may take the form of cracking and complete failure of the metal.

When cracking occurs in the *region of acid attack*, it is mainly transcrystalline in character so far as can be determined, and occurs always in areas where the metal is under severe stress. Examples of this type of cracking are the cracks that develop in drum heads, headers, etc. In the water contacting the metal at these points of failure no postulation is made of concentrations other than those in the boiler water. The two fundamental factors basic to this type of failure are the corrosion incident to a pH value less than 9.6, and stresses, and probably cyclic stresses, in conjunction therewith. There is no need to postulate stresses above the endurance limit as determined in air, because failure by corrosion-fatigue, which this type of cracking represents, may occur at stresses only a fraction of the endurance limit.

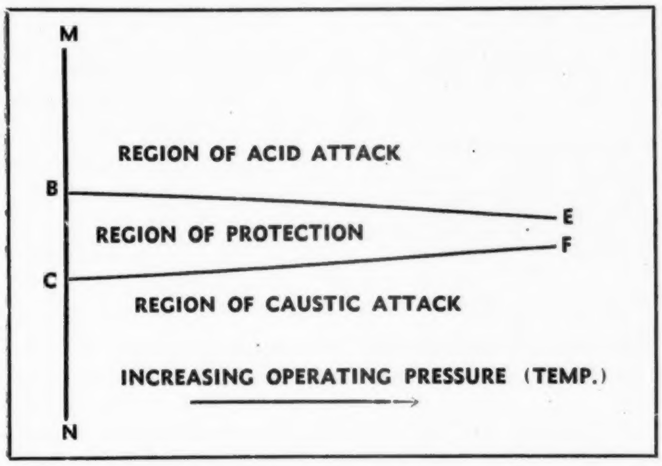


Fig. 1—Effect of increasing operating pressure (temp.) on the region of protection

Since the stresses built into the boiler are unalterable, prevention must rest upon control of the pH value in the water. It is the experience of the author that consistent, careful control of pH value is remarkably effective in staying any progress of cracking, as well as preventing its initiation.

Limitation of Boiler Water Alkalinity: Because caustic in the boiler water is desirable only to that small and limited concentration necessary for the control of the pH value and to the most effective use of the treating chemicals, the alkalinity of the boiler water should correspond to a position in the *region of protection* lying slightly below the line BE. Greater amount of caustic than this is undesirable because of its augmentation of any foaming tendency of the boiler water, and because fewer concentrations thereof will change the locus of the boiler water from within the *region of protection* to that of the *region of caustic attack.*

In earlier days, when soda ash was depended on for final treatment of the boiler water, control of boiler water alkalinity presented difficulties because it was not an independent variable of itself, but varied with the concentrations of treating chemical. Because of the rapid decomposition of soda ash into caustic in the boiler water, boiler water alkalinities were bound to run high. We find this state of affairs reflected in the Boiler Code, which states:

> "It is recommended that the concentrations of free sodium hydroxide and sodium carbonate within all steaming boilers be kept in excess of 15 gr/gal. (255 p.p.m.) in terms of sodium carbonate."

As a matter of fact this recommended minimum of 255 p.p.m represents considerably more than the maximum alkalinity in large numbers of the well-operated boilers of the country. With use of phosphate as the final conditioning chemical on the boiler water, any difficulty in maintaining the low desired alkalinities disappears, because under these conditions both the phosphate and the alkalinity in the boiler water represent independent variables.

With proper consideration given therefore to the potential alkalinities in the feed water, no difficulty whatever is encountered in holding the boiler water within the *region of safety* and at the desired proximity to the line BE. With the maintenance of this desirable low alkalinity in the boiler water, comes simplicity in the maintenance of the recommended sulphate-alkalinity ratios for prevention of the caustic type of corrosion that will be considered next. In many cases I suppose the attempt has been made to lower alkalinities and introduce sulphate by use of sulphuric acid as a treating chemical. It is our belief that an acid treatment of this sort should not be used unless placed under the careful supervision of capable chemists, who are given the time and the essential equipment to carefully control the addition of acid and the further equipment to effect its homogeneous distribution through the water. For our own part, through consideration of this problem of obtaining low alkalinities in the boiler water with safety by the usual operators, we have developed the use of an alkali-reducing form of phosphate, which is not acid as it is introduced into the water, but which upon arrival in the boiler and at boiler water temperatures gradually transforms into its alkali-reducing form. This development has been of special service to us in this problem of controlling boiler water alkalinities at the low concentrations desired.

Caustic Corrosion Cracking: Under this heading we include those types of failure that are sometimes called "caustic embrittlement," or merely "embrittlement." They are characterized by the fact that the cracking is largely intercrystalline in character. This type of failure occurs in the *region of caustic attack.*

The *region of caustic attack* represents concentrations of caustic beginning perhaps at approximately 8 per cent or lower and extending on up. Therefore this type of attack frequently occurs in caustic evaporators at various points, but in boilers is limited to those sections in which there is possibility for highly concentrating the ordinary boiler

waters. In a boiler therefore this type of failure will be found in seams, around rivets, etc.

The same types of stresses that in conjunction with corrosion are effective in producing cracking failure in the *region of acid attack*, are effective in the *region of caustic attack* as well. The difference in manner of attack in the latter region is due to the fact that caustic is probably the corroding agent in this case. We have explained elsewhere[2] why the attack is largely localized at the grain boundaries. The hydrogen developed in this attack causes transient brittleness, strictly comparable with the brittleness developed in an acid pickling bath. The grain boundaries thus become the line of least resistance, and the stresses concentrated at the point of advancing corrosive action cause cracking along these lines. Simultaneity of corrosion and changing stresses causes failure at stresses only a fraction of the endurance limit.

When mercury amalgamates with copper, it preferentially seeks the grain boundaries. When stress is applied the break occurs along the grain boundaries. Cracking in the field of caustic attack seems to us entirely analogous.

Analysis of Deposits from Seams of Boilers

The effect of concentrated caustic simultaneous with stress on the metal is well known and has been widely discussed. To the author's knowledge there has never been presented an analysis of deposits actually found in the seams of a boiler that exploded. The following analyses present such data and with them the analysis of a deposit taken from the corresponding seam in the boiler alongside in the same row from which the butt strap was removed, but in which not the slightest sign of any cracking could be found. Table 1 presents the analysis of the raw water used for feed water. It comes from a pond fed by surface drainage whose shallow shore waters are thoroughly choked by organic growth. Table 2 gives the average of the caustic alkalinity in these boiler waters averaged by months for the year preceding the explosion. The sulphate concentrations were low.

Boiler No. 6 exploded. Boiler No. 3 blew out one header on hydrostatic test at 325 lb. pressure. Boiler No. 5 on minute examination showed no evidence whatever of cracking. Boiler No. 4 was never examined or tested, while boilers Nos. 2 and 1, both on hydrostatic test and on careful examination, showed no evidence of cracking.

Table 3 gives the analyses of deposits, with description of the joints from which they were taken The remarkable thing about all of these deposits is the low content of both caustic and sodium carbonate. It would not be surprising to have low content of caustic if the sodium carbonate were high, because the gradual change of caustic into sodium carbonate is well recognized, but if caustic were concentrating in these seams one would certainly expect to find a goodly percentage of soda ash at least. The distinguishing feature of No. 1 analysis of the sample from the boiler that exploded is the high content of sodium chloride. The distinguishing feature of No. 4 analysis from No. 5 boiler, in which cracking could not be found, is the low content of sodium chloride and the high percentage of the general corrosion product, iron oxide. The character of these deposits as shown by their analyses, in conjunction with the fact that in only two boilers out of a row of six operating under similar conditions was deterioration noted, while three of them upon examination showed no such deterioration, would seem to indicate rather

[2] N. E. L. A. Bulletin No. 051, Treatment of Feed Water, pp. 5-12, 1930.

TABLE 1. Raw Water Supply to Boiler House

	Parts per million	Equivalents per million
Bicarbonate (HCO_3)	46.7	0.77
Sulphate (SO_4)	3.1	0.06
Chloride (Cl)	22.1	0.62
Phosphate (PO_4)	trace	—
Silica (SiO_3)	6.2	0.21
Iron (Fe)	1.4	0.08
Calcium (Ca)	13.7	0.69
Magnesium (Mg)	3.9	0.32
Sodium (Na)	13.8	0.60
Suspended Material	9.9	
Organic	considerable	

TABLE 2. Caustic Alkalinity, gr. Sodium Carbonate per Gallon, Averaged by Months

Month	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
June, 1928	32	31	43	22	45	31
July	32	34	39	30	47	28
Aug.	31	34	43	34	48	34
Sept.	37	33	37	34	47	38
Oct.	43	33	37	37	45	35
Nov.	49	38	43	35	44	36
Dec.	42	37	36	37	37	42
Jan., 1929	34	42	41	39	41	25
Feb.	33	40	35	39	41	36
Mar.	35	36	39	37	40	31
April	32	33	40	28	43	37
May	34	42	32	30	39	26
Average	36	36	39	33.5	43	33

TABLE 3. Deposits from seams of Boilers

Analyses in Per cent	1(a)	2(b)	3(c)	4(d)
Water Soluble				
Water	2.6	4.7	4.1	1.6
Sodium Carbonate (Na_2CO_3)	1.2	3.6	3.4	0.3
Caustic Soda (NaOH)	0.4	3.0	2.8	0.1
Sodium Chloride (NaCl)	61.3	10.1	10.7	2.7
Sodium Sulphate (Na_2SO_4)	5.5	1.4	2.4	trace
Water Insoluble				
Sulphur Trioxide (SO_3)	trace	trace	0.4	trace
Carbon Dioxide (CO_2) (approx.)	1.3	10.9	14.1	11.4
Phosphorus Pentoxide (P_2O_5)	trace	0.6	0.2	trace
Silica (SiO_2)	3.4	17.6	14.2	22.3
Iron Oxide (Fe_2O_3)	6.1	10.6	5.0	47.0
Calcium Oxide (CaO)	1.7	17.3	17.9	14.4
Magnesium Oxide (MgO)	0.2	3.9	1.0	1.1
Organic and Undetermined	16.3	16.3	23.8	—

(a) *No. 6 boiler* blew up. Deposit was taken from between inside butt strap and drum sheet, and along the line of the cracking between rivet holes.
(b) *No. 3 boiler* failed at a header seam at 325 lb. hydrostatic pressure during a hydrostatic test. Sample taken from leak at junction of header seam and drum butt strap.
(c) *No. 3 boiler.* Sample taken from outside of drum butt strap near where head failed.
(d) *No. 5 boiler* did not fail. On removal of the butt strap corresponding to the one that failed on No. 6 boiler, careful examination failed to reveal any cracking or indication of cracking. Sample taken from between the butt straps along the front longitudinal seam when the outside strap was removed.

clearly that the heritage of stresses acquired during assembly of the boiler featured largely in the events leading to its final destruction.

Means of Prevention

From the experiences of observation over quite a period of years now, two methods of insurance against cracking of this type seem well established: (a) The mechanical prevention of continued contact of concentrated liquid caustic or any other component of the boiler water with the boiler metal. (b) The erection of a protective barrier between the metal and concentrated boiler water established and maintained by the chemical relationships in the boiler water. Where new boilers are going in both methods can be made effective. On the boilers that are installed it often happens that the mechanical element of protection is lacking and dependence must therefore be based on the chemical factor alone. We will discuss these two methods briefly.

(a) Mechanical Prevention: Internal caulking only is, we believe, the most fundamental mechanical protection that can be given to a boiler. Both experience and theory unite in support of this statement. No better proof of experience could be given than the statement by Southern California Edison[3]. On the side of theory, Thiel[4] has elegantly presented the facts of concentrating boiler waters in seams. There are two good reasons why inside caulking must be so effective. First, perhaps under this condition concentration will not occur readily in the seam. Second, if concentration does occur, the evaporation of the boiler water goes on to complete dryness, thus avoiding any chance that concentrated liquid caustic or other component remains indefinitely in contact with the metal. A simple allusion illustrates this. Suppose we evaporate two pots of syrup, one open and one closed, over the same constant heat. Even though this heat be low, the open pot readily goes to the solid state, while the closed pot remains liquid. This is as it should be, since the evaporated vapors are swept away from the open pot while in the closed pot they are retained to impede further evaporation. The open pot corresponds to inside caulking only, the closed pot to the conditions developing in the seams when there is outside caulking.

Thus we come to the conclusion that with inside caulking only there is little chance that caustic or other component in the concentrated boiler water will have opportunity to be effective for corrosive action on the metal, and that therefore this type of caulking is an extremely effective mechanical protection against caustic corrosion cracking. Another advantage inherent in this type of caulking is the high character of workmanship on butt straps and rivets which is a prerequisite for its success.

(b) Chemical Relationships in the Boiler Water: The corrosion factor effective in the *region of caustic attack,* can be removed if a protective impermeable barrier can be established between metal and water and maintained by so adjusting the chemical relations in the boiler water that as concentration of the water occurs it adds to, rather than subtracts from, the barrier already established. The question therefore becomes, how to establish this barrier with certainty.

Practice and theory again unite in supporting the certain protective function of a barrier composed of dense, solid sodium sulphate deposited from the boiler water. In operating practice the absence of deterioration in many boilers attests the protective action; in experimental practice the work of Parr and Straub[5] is just as definite. On the theoretical side the work of Brennan[6], demonstrates the impermeable character of the sodium sulphate barrier.

The establishment of recommended sulphate-alkalinity ratios in the boiler water therefore has the significance of providing those conditions under which sodium sulphate will precipitate on the surface of the metal as an impermeable barrier before the caustic concentrates sufficiently that its corrosive action may be deleterious. Under this interpretation of the ratios, and in view of the known solubility curve of sodium sulphate and its ready precipitation as a more insoluble body at higher temperatures, it seems likely that the protective ratios for boilers operating above 400 lb. pressure should be no more, and probably less, than for those operating in the range up to 400 lb.

By the maintenance of the proper sulphate-alkalinity ratios we provide by chemical means thoroughly dependable mechanical protection to the boiler metal. When the alkalinities in the boiler water are given the low value and the exact control that are possible with our present knowledge of water conditioning, no difficulty attaches to the maintenance of recognized sulphate-alkalinity ratios.

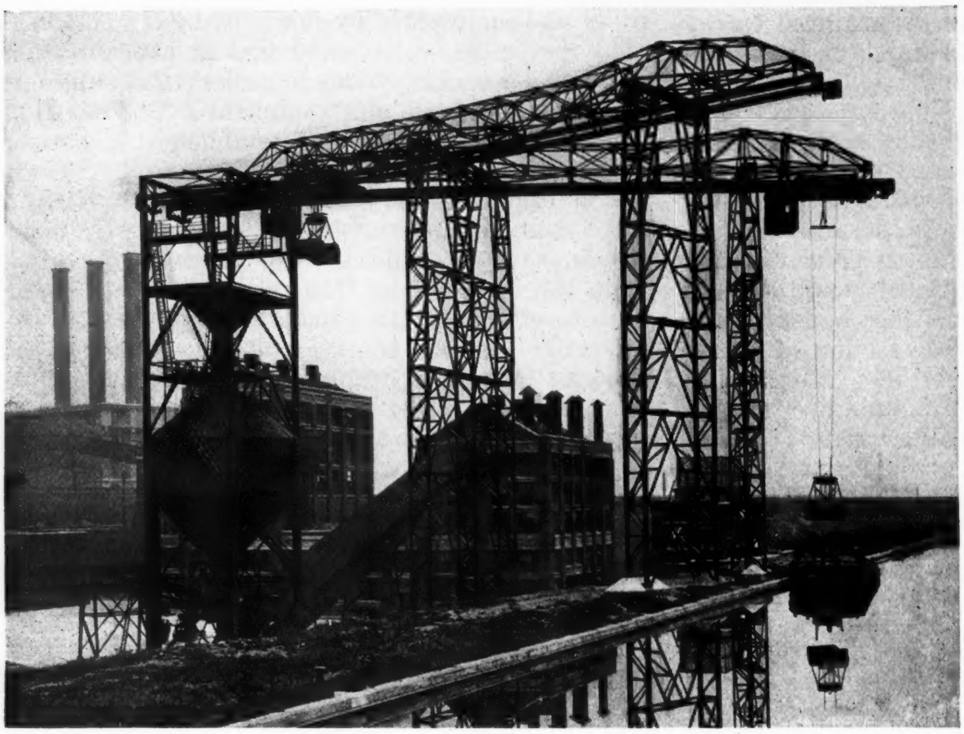
Other protective materials have been proposed, as for instance, phosphate, chromate, and some organic materials. In the protective action of none of these is there a definite, clear-cut picture of the protecting impermeable barrier, nor of how it shall be maintained with complete certainty, as is the case with sodium sulphate. On the contrary, there are reasons in every case to doubt the certainty and efficacy of protection.

Table 3 for instance, illustrates plenty of organic matter derived from the aquatic growth in the pond which has been present in contact with the metal because found in the deposits in the seams. Perhaps the specific type of organic matter was wrong, but degradation of all organic bodies into divers substances is accelerated by temperature (operating pressure), and placing dependence thereon for safety is equivalent to building foundations on shifting sands.

The chromates are very protective against corrosion by their formation of a thin, protective film whose permanence of protective action depends

(Continued on page 54)

[3] Prime Movers Report No. 256-71, 1925.
[4] "Speisewasserflege," 1926, p. 115.
[5] Bull. 177, University of Illinois Engineering Experiment Station.
[6] Byllesby Management, 1928.



General view of Kirkstall plant showing the power station in the background and the coal pulverizing and treatment buildings together with coal unloading equipment in the foreground

The New Kirkstall Power Station at Leeds

Details of One of the Most Recent and Modern British Power Stations

By DAVID BROWNLIE, London

While the new Kirkstall station described in this article is not large from the standpoint of American practice, it has a number of interesting features and its design throughout reflects the most modern development. In this respect, it is typical of practically all the newer British and Continental power stations . . . . . This article is believed to be the first official description of the Kirkstall station to be published either in this country or abroad. Eventually Kirkstall will play an important part in the power system of Northern England.

THE Corporation of Leeds has recently completed the first 50,000 kw. section of its new Kirkstall power station which is to be a main base-load station in the scheme of national electrification. The construction of this station, designed for an ultimate capacity of 150,000 kw., was necessitated by the fact that the Corporation's Whitehall Road Station was being taxed beyond its capacity. At the present time, the Kirkstall tatiosn is only supplying 17,000 kw. but the full capacity of the first section will shortly be available and the station connected to the "grid system."*

The design of the Kirkstall station exemplifies the most modern practice throughout. Several features are of particular interest. The boilers are fired with pulverized fuel using the bin, or storage, system and horizontal turbulent burners of recently developed design. Long rotary driers are installed for predrying the coal which has a high moisture content. The pulverizing equipment and driers are located in separate buildings, the coal being delivered from the pulverized coal bunkers in the preparation plant to storage bins in the boiler house by means of an air transport system. Centrifugal dust collectors are installed for removing dust from the chimney gases. The control equipment includes fully automatic control for the boiler units, a remote electrical control system for the steam valves and a new design of signal system for the generating equipment.

The site of the plant is on the Redcote Farm Estate, near the south bank of the River Aire, at a point between Armley and Kirkstall, suburbs of Leeds. This estate is about 104 acres in extent, and belongs to the Corporation. In the immediate

* The term applied to the high voltage transmission system under British Government Supervision.

neighborhood there is still in existence the ruins of the famous Kirkstall Abbey, which was partially destroyed in the reign of Henry VIII, at the Dissolution of the monasteries, the Abbey and the grounds being now a public park. In general the site is very well situated as regards coal, being served by the London, Midland and Scottish Railway, the Leeds and Liverpool Canal, with connections to the Aire and Calder Canal. A new dock has been built to accommodate 50 coal barges.

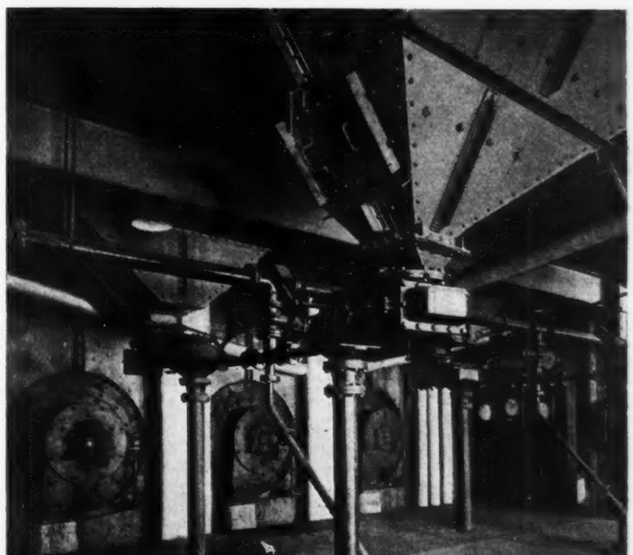
For unloading the canal barges, there is an equipment of two telpher tracks and telphers, each of 40 tons per hr. capacity, the coal being lifted to 50 ft. and then caused to travel along a track 144 ft. in length, with discharge through an automatic weighing machine at the rate of 60 tons of coal per hr., into a 300-ton raw coal bunker. From this bunker the coal is taken by either of two belt conveyors and passed to the wet coal bunkers in the drier house or to a storage pile. These belt conveyors are 18 in. wide and travel at 180 ft. per min., with a capacity of 40 tons per hr., the storage pile conveyor being 570 ft. long.

The drier house contains three Ruggles-Cole A. 12 complete drier units of the long, cylindrical, externally heated type, made by Head Wrightson and Co., Ltd., Stockton, 45 ft. in length and 6 ft. 10 in. dia., driven at 6 r.p.m. by a 35 hp. motor through four sets of gearing. The capacity of each of these driers is 12 tons of dry coal per hour, the moisture content of the coal being reduced from 15 per cent down to 3 per cent. The reason for the use of separate driers is the high moisture content of the coal, which averages 15 per cent and is often more. This type of drier consists of a shell formed of two concentric steel cylinders, slightly inclined to the horizontal, and operated with a hand-fired furnace, the combustion gases passing through the concentric space on the counter-current principle. A series of lifting plates are fitted inside to lift up and shower down the coal. To each drier there is connected an exhaust fan of 10,000 cu. ft. capacity per minute with gases at 150 deg. fahr. and operating at 2½ in. of water, the gases being passed to a centrifugal dust collector. The coal is taken from the driers by duplicate screw conveyors to two elevators, from which it is delivered to two further screw conveyors which carry it to the dry coal bunkers over the pulverizers. The total capacity of these bunkers is 200 tons.

The pulverizers, three in number, are of the Raymond "super mill" 6-roller type, each having a capacity of 15 tons of dry coal per hour and pulverizing to a fineness of 85 to 90 per cent through a 100 mesh and 100 per cent through a 40 mesh screen. After leaving the cyclone classifiers, with which the mills are equipped, the pulverized coal passes through an automatic weighing machine to the pulverized coal storage bunkers which have a capacity of 200 tons. These connect by suitable valves to two pulverized fuel pumps and compressed air transport units which transport the material to the storage bunkers over the boilers, each boiler having a bin storage capacity of 60 tons. The pulverized fuel pumps are the screw feed type and are capable of handling 40 tons of coal per hr. Two motor-driven air compressors provide the compressed air to transport the coal.

The coal preparation building is connected to the main power station by a 5-space bridge, 10 ft. wide which carries the pipes through which the pulverized coal is blown to the boiler house bunkers and which also carries the electrical cables. The main contractor for the coal preparation plant, including the buildings, and for the equipment in the boiler house is International Combustion, Ltd., London.

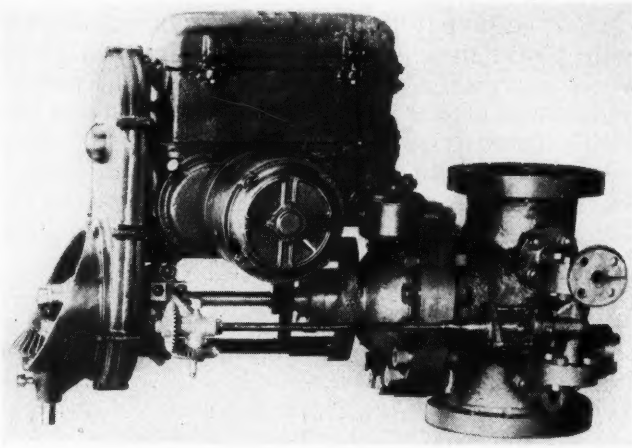
The boiler house is 75 ft. high, 76 ft. wide, and 142 ft. long. At present, there are three Stirling boilers installed each having three drums 42 in. dia. by 32 ft. long, weighing 14 tons, of seamless forged steel, 1¾ in. thick, with separate fabricated ends riveted to the shells. Each boiler has 848 main tubes, 3¼ in. external dia., with a total heating surface of 16,540 sq. ft. The operating conditions are as follows: pressure—490 lb. per sq. in., normal evaporation—160,000 lb. per hr., overload—184,000 lb. per hr. The firing equipment for each boiler consists of three "R" type, No. 70 burners for horizontal firing. Eighty-five per cent of the preheated combustion air is admitted through ports around the burner, and the remaining 15 per cent which serves as the carrying air for the coal, enters through the burner with the coal. These burners are rated at 70,000,000 B.t.u. per hr. each, the three burners installed per boiler having a combined capacity of 22,400 lb. of coal per hr. normal and 26,350 lb. maximum. The furnace side walls and rear walls are entirely water-cooled on the Mur-



Partial view of boiler room at burner level

ray-Usco principle, and a plain tube water screen is installed above the ash pit. The furnace volume is 11,000 cu. ft., the height above the water screen being 36 ft. at the front and 20 ft. at the back, the width 27 ft. 6 in., and the depth from front to rear 15 ft. The heating surface of the rear wall is 575

sq. ft., the side walls, 585 sq. ft. each and the water screen, 330 sq. ft., making a total of 2075 sq. ft. Each boiler is equipped with an "M.L.S." multiple-

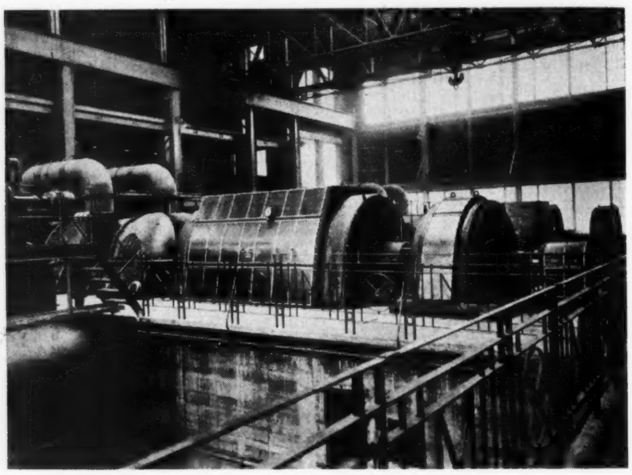


Electrically controlled steam valve

loop, single pass superheater of 2950 sq. ft. of heating surface, giving a total steam temperature of 750 deg. fahr., a Foster economizer having a heating surface of 6480 sq. ft. and arranged 9 rows high and 12 rows wide, and a Ljungstrom air preheater with a rotor speed of from 3 to 4 r.p.m.

All the mountings are by Hopkinsons of Huddersfield who have also supplied a complete equipment of remote controlled electrically operated steam slide valves with control panel, the turbine room signal system, steam traps, water valves, and "Duo" feed water regulators.

The general arrangement of the electrically controlled steam valve consists of a valve, small self-contained a.c. motor, limit switches, wiring and panel equipment. Some of the obvious advantages of this arrangement are, the immediate closing-down of all or any of the valves in an emergency, more accurate control of the whole plant, and, in

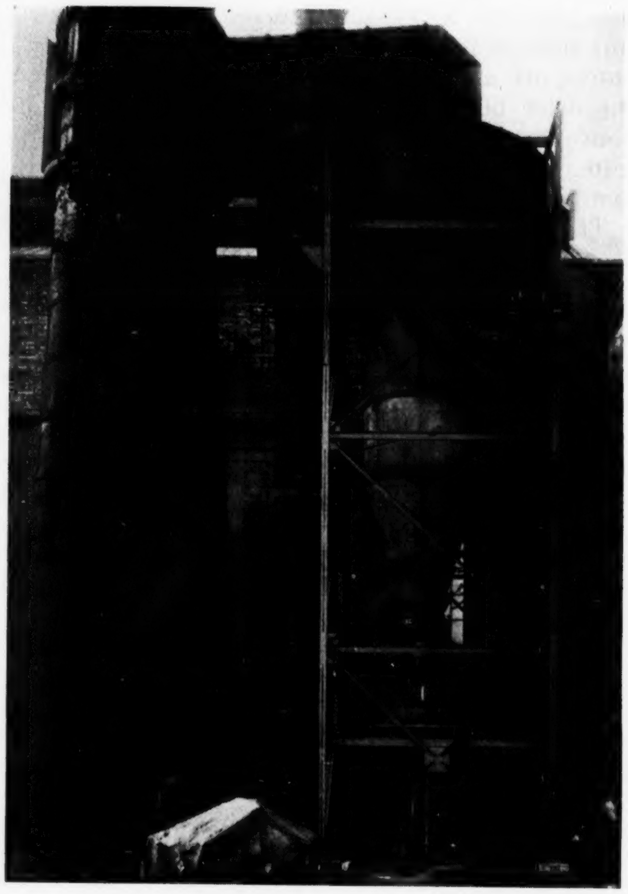


View of generator room showing two 25,000 kw. turbo generators

the case of large high pressure valves, the elimination for regular use of heavy, complicated, and slow moving reduction gear for hand operation. Where necessary, hand operation is always possible as the driving motor is automatically disconnected as soon as it stops running.

All the primary and secondary air fans are of Sirocco make, by Davidson and Co., Ltd., of Belfast. Each boiler has two 57 in. dia. induced draft fans, each rated at 52,200 cu. ft. of hot gases per minute, 325 deg. fahr. against 2½ in. of water, driven by a direct coupled 135 hp. motor running at 725 r.p.m.; also with a 46½ in. dia. double inlet forced draft fan of 62,200 cu. ft. of air per min. capacity at atmospheric temperature against 3 in. of water, direct driven by a 96 hp. motor at 370 r.p.m.

The dust collectors are also of Davidson make, "D" type, on the combined centrifugal and gravity



Installation of flue dust corrector similar to that installed at Kirkstall

principle, one collector being installed for each induced draft fan. More than 100 power stations in Great Britain and abroad are now equipped with these dust collectors, introduced several years ago, and, as stated, from 70 to 95 per cent of the total dust in the combustion gases is taken out without using water jets or lowering the temperature. Performance details with regard to Kirkstall will not be available until the station is on full load but the screen analysis of the dust now being separated is 93.8 per cent through 100 mesh, 77.4 per cent through 200 mesh, 64.4 per cent through 250 mesh, and 53.2 per cent through 325 mesh.

Ash handling is on the Hydrojet principle, using jets of high velocity water which periodically

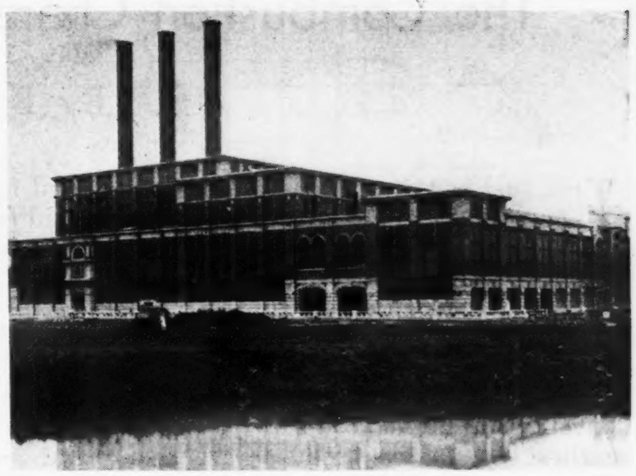
wash the ash into a trench in the basement of the boiler house, from which it is pumped to an outside storage dump.

The turbine house, one-third now completed, but with provision made for an additional 100,000 kw., is 83 ft. high from the basement level to the overhead crane rails, 84 ft. wide between the crane rails, and 144 ft. long. Equipment includes an overhead traveling crane of 100 tons capacity.

The main a.c. turbo-generator sets of 25,000 kw. are of the pure impulse type in the high pressure section, which has 16 stages, while the low-pressure section is on the double flow reaction principle, running at 3000 r.p.m., with standard operating conditions of 450 lb. per sq. in. pressure and 720 deg. fahr. superheated steam temperature at the stop valve. These units were manufactured by the British-Thomson-Houston Co., Ltd., of Rugby and have stainless steel blading and pressure lubricated oil bearings. Lubrication is accomplished by means of a main oil pump fitting with positive gear drive from the turbine shaft, but there is also a secondary turbine-driven oil pump which comes into operation when the oil pressure falls below some pre-determined figure. Each turbine has three oil coolers, one of which is a standby, and a centrifugal oil purifier.

The turbine is coupled to an a.c. generator through a flexible coupling of the "claw" type; cooling air for the generators is supplied by a fan mounted on an extension of the main rotary shaft. The main condensers are of special design on the regenerative principle, for dealing with the very difficult water of the River Aire, each set having a centrifugal circulating pump of the Allen (Conqueror) type, of 2,400,000 gal. per hr. capacity.

The Hopkinson turbine room signals operate on the push-button principle. The attendant has no need to take his attention from the board, each button for one corresponding instruction having also



Kirkstall power station

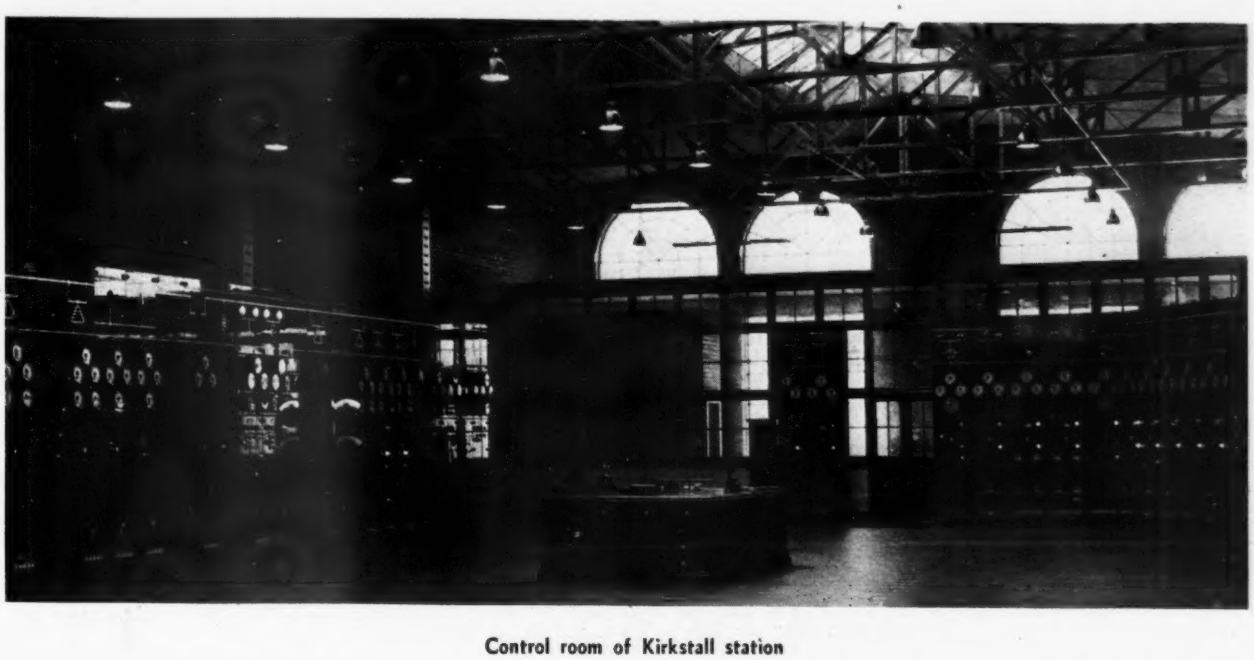
a different electric circuit, instead of using complicated wiring.

The main contractors for the complete generating plant are the British-Thomson-Houston Co. Ltd., with W. H. Allen Sons & Co., Ltd., of Bedford, as sub-contractors, who have supplied the condensing equipment.

The feedwater arrangements are on the closed circuit principle, each boiler having three Weir feed pumps of the steam turbine-driven type with exhaust passing to the feedwater. Each pump is capable of supplying 50 per cent of the maximum boiler feed requirement, one being a standby, but interlocked to come into operation automatically as desired, while a 3-stage feedwater heating plant is provided to raise the temperature of the feedwater to 300 deg. fahr. Makeup water is provided by double-effect coil and pipe evaporators with bypass and change-over valves.

Of particular interest are the switchgear arrangements with control from a fine central hall, containing the operating panels, periodicity and pres-

(Continued on page 54)



Control room of Kirkstall station

The Combustion Characteristics of Producer Gas

By B. J. CROSS

THE fuel bed of a hand fired or stoker fired furnace is actually a gas producer. The solid fuel is gasified by distillation and partial oxidation, and the resultant combustible gas that is formed is burned in the space above the fuel bed. If we separate the fuel bed from the furnace and conduct the combustible gas formed in the fuel bed to the place or places where it is to be burned, we will have essentially a producer gas installation. The earliest types of gas producers were air blown only. The heat value of the gas was low and the quality was not uniform due to difficulty in maintaining a uniform fuel bed. All modern gas producers introduce steam with the air in the proportion of about .5 lb. of steam per pound of coal. About one half of this steam is decomposed, reacting with the hot carbon to form hydrogen, carbon monoxide and methane. These gases increase the heat value of the producer gas and the reactions being endothermic, serve to reduce the fuel bed temperature and tend to prevent clinkering.

In steam production there is seldom a net advantage in the separation of the fuel bed and furnace and producer gas is rarely used as a fuel for steam boilers. The chief application of producer gas is in processes where coal or other solid fuel cannot be used directly. The advantages of producer gas firing are (a) Absence of ash and objectionable forms of sulphur. (b) Close control over temperature. (c) Control of furnace atmosphere. (d) High temperatures due to high possible preheat of air and gas. There is always a loss of heat in the formation of producer gas. If the gas is scrubbed, about 75 per cent of the heat in the coal will be delivered in the producer gas. If the gas is used hot and uncleaned, it may contain as much as 90 per cent of the heat in the coal.

The principal applications of producer gas are in open hearth furnaces, glass furnaces and ceramic kilns. The processes involved in these applications are heat treatment rather than heat absorption and the products of combustion leave the furnaces at high temperatures. Heat recuperators and regenerators are, therefore, almost invariably used and the air for combustion and often the producer gas also is preheated to temperatures as high as 1200 deg. fahr.

The fuel for gas producers may be bituminous coal, anthracite, coke or even wood. The most common fuel, however, is bituminous coal. An average analysis of producer gas from bituminous coal, dry basis, is given in Table 2. When producer gas is washed, the heat value as calculated from the analysis is its true heat value. Its water vapor content is that corresponding to saturation at its temperature. Hot producer gas contains soot and undecomposed tar which add to its heat value. The determination of the amount of this material in the gas is difficult. It is estimated that the presence of tar and soot in producer gas may add 10 to 15 B.t.u. per cubic foot to the heat value of the gas.

When producer gas is fired hot, the sensible heat in the gas above 60 deg. fahr. should be added to the heat value as determined by analysis. Thus in the analysis given the heat value of the gas is 2520 B.t.u. per lb. This is the amount of heat that would be evolved if gas at 60 deg. fahr. were burned and the products of combustion were cooled to 60 deg. fahr. If the gas temperature were 1200 deg. fahr. and the products of combustion were cooled to 60 deg. fahr., the heat evolved would be 2520 + (1200 — 60) × specific heat. For the purpose of this correction the specific heat of the gas may be considered .25 without much error.

In Table 1 the volumetric analysis of the gas given in Table 2 has been converted to a gravimetric basis and the ultimate analysis computed. The combustion characteristics of this gas is given in the chart on the opposite page. It should be noted that the products of combustion do not include undissociated steam. If .5 lb. of steam is supplied per pound of coal about one half of it will be decomposed. As approximately 4 lb. of producer gas is made per pound of coal, the undissociated steam will amount to about .06 lb. per pound of gas.

TABLE I

	(a) Per cent by Volume	(b) Molecular Weight	(c) Proportion by Weight (axb)	(d) Per cent by Weight	Ultimate Analysis, Per cent by Weight C	H_2	O_2	N_2
Carbon dioxide CO_2	5.0	44	220	8.70	2.37	...	6.33	...
Carbon monoxide CO	24.0	28	672	26.60	11.40	...	15.20	...
Hydrogen H_2	12.0	2	24	.95	...	.95	...	...
Oxygen O_2	.5	32	16	.65	...	...	.65	...
Methane CH_4	3.5	16	56	2.20	1.65	.55	...	...
Ethylene C_2H_4	1.0	28	28	1.10	.94	.16	...	...
Nitrogen N_2	54.0	28	1512	59.80	...	...	...	59.80
Totals	100.00	..	2528	100.00	16.36	1.66	22.18	59.80

Average molecular weight = 25.28——Cu. ft. per lb. at 60 deg. fahr. = 379.5 divided by 25.28 = 15.01——B.t.u. per cu. ft. at 60 deg. fahr. = 168——B.t.u. per lb. = 2520.

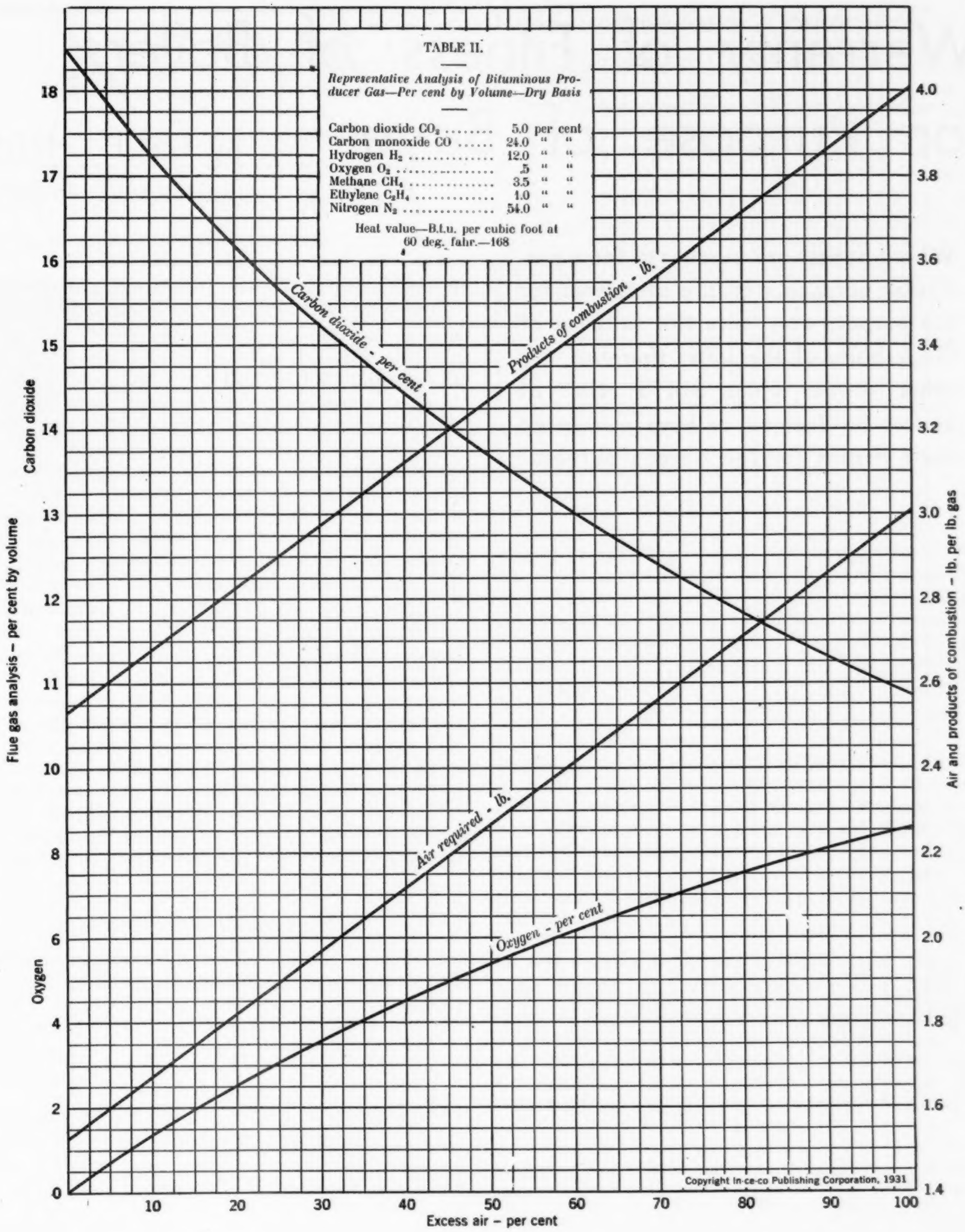


TABLE II.

Representative Analysis of Bituminous Producer Gas—Per cent by Volume—Dry Basis

Carbon dioxide CO_2	5.0	per cent
Carbon monoxide CO	24.0	" "
Hydrogen H_2	12.0	" "
Oxygen O_2	.5	" "
Methane CH_4	3.5	" "
Ethylene C_2H_4	1.0	" "
Nitrogen N_2	54.0	" "

Heat value—B.t.u. per cubic foot at 60 deg. fahr.—168

CHART SHOWING COMBUSTION CHARACTERISTICS OF A REPRESENTATIVE PRODUCER GAS FROM BITUMINOUS COAL

No. 22 of a series of charts for the graphical solution of steam plant problems.

Warranty of Fitness of Boilers for Purpose of Buyer

By LESLIE CHILDS
Indianapolis, Indiana

Where boilers are purchased for a particular purpose a failure of fitness for the purpose may raise the question of the liability of the seller therefor. In other words, when will a seller of boilers be deemed to have warranted their fitness for the buyer's purpose?

THE question of the liability of a seller of boilers or similar equipment for their failure of fitness for the buyer's purpose is one of peculiar importance to industrial executives. As may be expected the point has been the subject of considerable litigation, and the general rules as laid down by the courts may be summarized as follows.

The seller of a boiler will be liable for its failure of fitness for the buyer's purpose, first, when he has expressly warranted the fitness, and, second, when the buyer has relied solely upon the judgment and recommendation of the seller in selecting boilers for a particular named purpose. On the other hand, the mere supplying an order for a named type of boiler will not render the seller liable in any way for its failure of fitness. For example:

Buyer Orders Boilers

In one well reasoned case of this kind, the defendant, a corporation located in Kansas City, Missouri, was in the market for two boilers to be used in its heating and power plant. In this situation, defendant got in touch with the plaintiff, a manufacturer of boilers, and after comparison with prices, character of workmanship, etc., signed a contract for the delivery of two boilers at $3,600 each.

When entering into this contract, defendant specified the form, size and material of each boiler, and, in addition, named the kind of safety boiler using a trade name. In other words, defendant ordered a known definite kind of boiler as understood by the trade, and no express warranty of fitness was demanded or required.

The boilers were delivered and installed according to the contract, but they failed to give satisfaction because of the character of the water used in them, i.e. the muddy water of the Missouri river. In operation the caps soon filled with sediment, which impaired the heating capacity as well as being a source of frequent repairs caused by their bursting and consequent interruption of operation.

Defendant called plaintiff's attention to this situation, and demanded that the latter remedy the matter. Plaintiff in turn denied any liability on the ground that he had manufactured the boilers in strict compliance with the order, and had in no way warranted their fitness for the defendant's purpose. As a matter of fact, there was no evidence tending to show that plaintiff had been called upon to make a warranty of this kind.

Defendant, however, took the position that since the plaintiff knew the purpose for which defendant was buying the boilers, and further knew the character of the water that would necessarily be used in them, they should be held to have impliedly warranted the boilers to stand up under the contemplated use. The dispute between the parties finally culminated in the refusal of the defendant to complete payment for the boilers, unless plaintiff made some adjustment. Plaintiff refused this and filed the instant action to collect in full.

The trial of the case in the lower court resulted in a judgment for the plaintiff on their demand. From this the defendant appealed, and the higher court, after reviewing the facts as they have been outlined, stated the general rules, in respect to warranty of fitness, as follows:

The General Rules Stated

"Where a manufacturer contracts to supply an article which he manufactures to be applied to a particular use of which he is advised, so that the buyer necessarily trusts to the judgment and skill of the manufacturer, there is an implied warranty that the article shall be reasonably fit for the use to which it is to be applied. * * *

"But where a known, described, and definite article is ordered from a manufacturer, although it be stated by the purchaser to be required for a particular use, yet, if the known, described, and definite thing be actually supplied, there is no implied warranty that it shall answer the particular purpose intended by the buyer. * * *"

Then, in applying the foregoing rules to the facts of the instant case, the court continued:

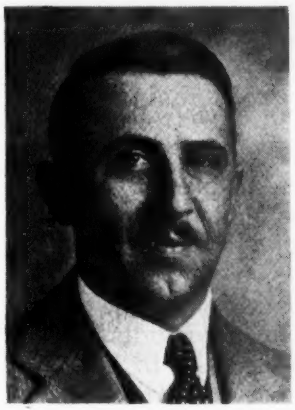
"Here the purchaser contracted for a definite, well-known kind of boiler * * *. The specifications as to size, form, material, and every detail were minute, and embodied in the contract. The manufacturer (the plaintiff) was obligated to deliver exactly such boilers as were described and

(*Continued on page 54*)

NEWS

Pertinent Items of Men and Affairs

H. W. Greider Heads Research Philip Carey Company



H. W. GREIDER

H. W. Greider has been appointed Director of Research for The Philip Carey Manufacturing Company, Lockland, Cincinnati, Ohio.

Mr. Greider was graduated in 1916 from Washburn College, Topeka, Kansas, and obtained the degree of M. S. in chemistry from Kansas University in 1917. He was an assistant chemist at Picatinny Arsenal, Ordnance Department, U. S. Army, during 1917 and 1918, engaged in development work on military explosives. From 1919 to 1927, he was an Industrial Fellow of Mellon Institute of Industrial Research, Pittsburgh, Pa., doing research and development work in the several fields of synthetic organic chemicals, rubber compounding and the physical properties of rubber, magnesia products and heat insulation manufacture. In the latter two fields he has been granted several patents for improved products and processes. In 1927 Mr. Greider entered the direct employ of The Philip Carey Company to continue work on magnesia products and heat insulations, supported by that company at Mellon Institute since 1924.

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Bernitz Furnace Appliance Company, Boston, Massachusetts, has announced the following changes in personnel.

Benjamin H. Snow has been appointed Division Sales Manager of the territory including the New England States, New York and northern New Jersey.

L. R. Leatherman, who has served the organization as District Manager in other territories, has been transferred to the New York office, 350 Madison Avenue, New York City, and with him will be associated F. G. Schneeberg, Jr., who has been assigned to sales work in upper New York and northern New Jersey.

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Illinois Stoker Company, Alton, Illinois, has appointed The Ashmead-Danks Company, Room 515, Rockefeller Building, Cleveland, Ohio, as its representative in the Cleveland district.

Third International Conference on Bituminous Coal

The Carnegie Institute of Technology announces a Third International Conference on Bituminous Coal to be held at Pittsburgh, November 16 to 21, 1931.

The purpose of the Congress is similar to that of the Congresses held in 1926 and 1928 by the Carnegie Institute of Technology: to present for discussion the results of recent studies of coal, emphasizing improved methods of utilization and their economic value. The program will include papers on the carbonization, liquefaction and gasification of coal; by-products; the mechanism of combustion; cleaning of coal and its preparation for the market; pulverized fuel; power plants; domestic heating, etc.

An invitation is extended to scientists of all countries to take part in this Conference.

Doctor Thomas S. Baker, president of the Carnegie Institute of Technology, has recently returned from Europe where he conferred with many of the leading fuel technologists. The participation of an even larger number of distinguished foreign and American scientists than were present at the two preceding Conferences is assured. The program will have an international as well as national significance.

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Goulds Pumps, Inc., Seneca Falls, New York, has announced the appointment of Mark D. Rowe as manager of the New York office, 16 Murray street, New York City, to succeed William H. Hopper. Mr. Hopper, after thirty-six years of service, has asked to be relieved of managerial responsibilities but has agreed to continue his identification with the New York office as a special representative.

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Morse Chain Company, Ithaca, New York, has announced the appointment of Walter W. Bertram as sales manager of the Industrial Chain Division. Mr. Bertram has been associated with the Morse Chain Company for eighteen years and has been New York manager for the past eight years.

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The Consolidated Coal Company, Inc., announces that John M. Wollmer has been appointed assistant to the vice-president in charge of sales, with offices at 15 Broad Street, New York City.

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W. S. Robertson, who became associated with Combustion Engineering Corporation in 1912, died suddenly of heart failure on March 31 at his home in Newark, New Jersey. Mr. Robertson was in his seventieth year and was actively engaged as special sales representative for northern New Jersey and eastern Pennsylvania until the time of his death.

Some Suggestions Regarding Harmonious Relationship between Boiler Water and Metal

(*Continued from page 45*)

upon the ability of the water in contact therewith to effect its repair whenever rupture occurs. The difficulty with use of chromate as protective agent in the boiler lies in the fact that chromates therein are rather readily reduced to chromic hydroxide in which form no protection is given. In this case again, uncertainty of protection undermines faith that protective action is continuously given.

The protective action of phosphate has been set forth by Straub, and there seems to be some tendency towards dependence thereon. However, Schneidewind[7], working with Professor White of the University of Michigan, has examined a case of caustic corrosion cracking occurring in a wrought iron hanger strap for a steam coil from a tank used for dissolving sodium phosphate. Failure occurred after eight weeks' operation at 140 deg. fahr., in a solution containing 55 per cent of commercial trisodium phosphate calculated on the basis of the anhydrous salt.

This apparent protective action of dilute, and destructive action of concentrated phosphate solution, seems anomalous, but one remembers that nitrates are similarly protective in dilute solution, but as demonstrated by Jones[8], are causative of cracking in their stronger solutions. So far as the author knows, no work in proof of any protective action of concentrated solutions of phosphate has been done; yet any usefulness of phosphate in protection from cracking depends on its concentrated solution. This follows because the caustic type of cracking occurs in the seams, and the requisite concentration of caustic to be deleterious in the seams can be arrived at only by multifold concentration of the caustic and necessarily likewise of the phosphate in the boiler water. In view of Schneidewind and White's work, and in absence of refuting evidence, it seems inadvisable to us to base protective measures on such uncertainty when the certainty of protective action by the sodium sulphate barrier is so well established and so readily maintained.

The authors believe it advisable that every boiler water be made to conform to the recognized rules so that in case of any unfortunate happening the one responsible for the boilers can point to his records as evidence of conformity to the rules.

Conclusion

The cases herein cited of corrosion, whether general or of the cracking type, have all of them required both chemical and mechanical features in their avoidance or correction.

Standing shoulder to shoulder, the mechanical engineer and the chemist must exercise their combined diligence to thwart the destructive agencies, ever ready to take their toll in the steam plants.

[7] Transactions American Society Mechanical Engineers, 1930.
[8] J. A. Jones, Trans. Farraday Soc., Vol. 17, Part I, p. 102, 1921.

Warranty of Fitness of Boilers for Purpose of Buyer

(*Continued from page 52*)

contracted for, and could not, under the contract, deliver anything different.

"There is no claim that the boilers did not in every respect conform to this contract and specifications, nor any claim that they were defective, either in respect to workmanship or material. The purchaser did not exact a warranty that the boilers would operate with the muddy waters of the Missouri river, and therefore assumed that risk himself. * * *" (78 Fed. 43)

Conclusion

In line with the above, the court concluded by affirming the judgment of the trial court in favor of the plaintiffs for the price of the boilers. This on the ground that since plaintiffs had not expressly warranted the fitness of the boilers, and had furnished them in strict compliance with the contract, the latter calling for a definite article, plaintiff had discharged his obligation in full.

Obviously, the foregoing case is one of great force and value on the subject dealt with. And, in the light of the facts and holding, it constitutes a clear-cut judicial announcement of the general rules applied in dealing with the question of warranties of fitness in cases of this kind. Truly, the case is one that may well be had in mind by executives in general, whether on the buying or selling end of a transaction involving the purchase or sale of boilers for use for a particular purpose.

The New Kirkstall Power Station at Leeds

(*Continued from page 49*)

sure regulators, operating battery, and other equipment. The switchgear is housed in a separate wing having a 20-ton capacity overhead crane and railway lines running through the building. The gear is of the totally enclosed compound-filled metal clad type, supplied by Ferguson, Pailin, Ltd., of Manchester. Every switchgear is in duplicate and is fitted with electrically operated tank removing gear. The main transformers connecting to the Whitehall Road station are housed in this building.

The entire project has been carried out to the designs and specifications of Mr. C. Nelson Hefford, Chief Electrical Engineer and Manager of the Corporation of Leeds Electricity Department, to whom the author is greatly indebted for information presented in this article as well as for the accompanying photographs.

It may be of interest to mention that the Leeds Electricity Department has about 100,000 consumers and 1400 employees, the maximum load being at present about 64,000 kw. with a sale of over 150,000,000 units per year.

REVIEW OF NEW TECHNICAL BOOKS

Any of the books reviewed on this page may be secured from In-Ce-Co Publishing Corporation, 200 Madison Avenue, New York

Uniflow, Back-Pressure and Steam-Extraction Engines

By Eng. Lieut. Commander T. Allen

SINCE about 1910 several interesting and specialized types of reciprocating engines have been developed, namely, the uniflow engine for condensing loads, the back-pressure engine for non-condensing loads, and the steam extraction engine for combined loads. The application of these prime movers is of great importance to industry as, even today, some form of reciprocating engine is to be found in the main industrial establishments, and the utilization of low-pressure steam, exhausted from the cylinders of steam engines, represents a highly efficient method for factories and other establishments in which there is a demand for heating or process steam in addition to the demand for power.

This book, which is written by an English author and based primarily on British practice, has two main aspects. One is concerned with the derivation and tabulation of the basic tables and curves of mean effective pressure, steam consumption, and mechanical characteristics which are essential to the designer for the correct proportioning of cylinders and other component parts to meet the wide variation in working conditions with regard to steam pressure, superheat, and load. The mechanical design of the three types of engines lends itself to a system of standardization, and the calculations, curves, and tables which appear in the book are based upon such a system.

The form in which the technical data is compiled is such as has proved most convenient in an actual design office, and the range of working conditions is that which is in common use at the present day. A few installations, however, have been made to utilize steam at a greatly increased pressure, and there are signs that this practice may spread, as the high efficiency and the absence of blading make the piston engine a suitable unit for incorporation at the high-pressure end of a turbine installation utilizing steam at exceptionally high pressure. Descriptions and illustrations of a number of high-pressure installations appear in the book.

The other aspect of the book is concerned with the method of application of the special types of engines, and with the description and illustration of the various engines which have been developed by leading manufacturers. Included in this material will be found examples of the design of each type of engine to suit typical working conditions taken from practice.

This book is 6 x 9 overall and contains 660 pages. The price is $10.00.

•

American Diesel Engines

By W. H. Morrison

THIS book discusses comprehensively all present-day Diesel engines built in the United States. Foreign Diesel engines are omitted, except for those designs which have been adopted by American builders, in order to hold the material within reasonable limits.

Among the topics discussed are the early history of American Diesel Engines, the economics of Diesel power, the various types of Diesel engines used in this country, their construction and operation, the relative costs of Diesel and steam plants, and the advantages of Diesel power for different applications.

This book is 6½ by 9¼ and contains 606 pages. The price is $5.00.

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Technical Bulletins

AMONG the interesting bulletins that have recently come to our attention are the following: *Combustion Tests with Illinois Coals,* Bulletin No. 213, price 30 cents, and *Embrittlement in Boilers,* Bulletin No. 216, price 65 cents, both bulletins being reports of investigations conducted by the Engineering Experiment Station, The University of Illinois, Urbana; also, *Strength of Brick and Tile Pilasters Under Varied Eccentric Loading,* Bulletin No. 55, price $1.00, and *Research in Dry-Press Refractories,* Part I, Bulletin No. 56, price $1.00, being reports of investigations conducted by the Engineering Experiment Station, The Ohio State University, Columbus; also, *A Study of Refractory Service Conditions,* Bulletin 334, price 50 cents, published by the Bureau of Mines, U. S. Department of Commerce; also, *Index to A. S. T. M. Standards and Tentative Standards,* no charge, published by the American Society of Testing Materials, 1315 Spruce street, Philadelphia.

NEW CATALOGS AND BULLETINS

Any of the following publications will be sent to you upon request. Address your request direct to the manufacturer and mention COMBUSTION Magazine

Automatic Control Instruments

New Catalog No. 8008 presents the complete line of Brown Automatic Control Instruments, including recording, indicating, signaling and alarm controllers for temperature, pressure, flow, etc. The catalog is divided into two general sections; the first illustrates the applicability of automatic control to various industrial processes and the second shows the instruments and discusses the principles of operation and details of design. 48 pages and cover, 8x10½—Brown Instrument Co., Wayne and Roberts Aves., Philadelphia.

Dead Weight Pressure Gage

A pressure gage which embodies dead weight tester accuracy and permanence of calibration, together with abundant power for the operation of remote type indicators and control devices, is described in new Bulletin No. 70—"Power Type Pressure Devices." While the principal use of this particular type unit is for the operation of a master steam pressure indicating or recording system, it also serves as a pressure gage and may be used for the operation of switches or the control of small valves, rheostats, etc., in accordance with pressure variations. 4 pages, 7¾x10½—Bailey Meter Company, Cleveland, Ohio.

Expansion Joints

FlexoDisc Expansion Joints, described in Bulletin No. 40, are designed to provide a simple and reliable means of compensation for material changes in the length of pipe lines caused by temperature changes. A standard FlexoDisc Expansion Joint consists of a flexible heat-treated alloy steel expansion element welded to flanged heads. There are no stuffing boxes nor gland bolts and since no packing is required, the joint is tight under all conditions. 4 pages, 8½x11—Croll-Reynolds Engineering Company, 17 John Street, New York City.

Feed Water Regulation

"Modern Copes Feed Water Regulation" is a new booklet presenting standard Copes equipment for controlling boiler feed water. No attempt is made to cover the many special adaptations of this equipment for unusual requirements. Of special interest in this booklet are the Type SLH Valve and the Type OT Regulator, both of which have recently been developed. The replacement of the compression type thermostat by one with the expansion tube in tension and the new specifications for Copes valves represent a definite improvement in this equipment. The catalog is well illustrated and the details of design, application arrangements and record charts are attractively shown in two colors. 16 pages and cover, 8½x11—Northern Equipment Company, Erie, Pa.

Flexible Couplings

Poole All-metal Flexible Couplings, suitable for fan and pump drives and similar service, are presented in a handsome new catalog No. 30 which is bound in cloth covers. These couplings carry their load on crowned gear teeth formed on the periphery of each shaft hub, which mesh with corresponding teeth on the interior of a floating connected sleeve which is fully enclosed and contains an oil bath thus insuring complete lubrication. The construction permits large surfaces and low unit stresses. Special couplings of various designs are available for special services. Typical installations are illustrated and complete dimension tables are included. 44 pages and cover, 6¾x9¼—Poole Engineering & Machine Co., Baltimore, Md.

Interlocking Fire Brick

Right Lock Fire Brick are the same size as regular 9 in. fire brick and are laid according to usual fire brick setting practice when building refractory furnace walls. These brick are provided with grooves so located and spaced as to provide interlocking between adjacent bricks and the bonding cement between them. A new leaflet illustrates the brick and recommended method for its use in building refractory furnace walls. 4 pages, 8½x11—Power Plant Efficiency Company, Union Title Building, Indianapolis, Ind.

Pressure Control Equipment

Bulletin H-2 presents twenty-one charts illustrating the results of various applications of Brooke Pressure Regulators. These applications cover gas pressure control, steam pressure regulation and combustion control for both stoker-fired and pulverized fuel-fired units. Brooke Regulators have been built for pressures ranging from 1500 lb. per sq. in. to .005 in. water column. 12 pages, 8½x11—Brooke Engineering Company, 3640 North Lawrence Street, Philadelphia, Pa.

Pulverized Coal Transport

The Fuller Lehigh Transport System for Pulverized Coal is illustrated and described in new Bulletin No. 903. In this system, the pulverized coal is aerated by compressed air and transported through a standard size pipe line, the flow being similar to that of a fluid. The system is automatic in operation. Designs are available for capacities ranging from one to one hundred tons of coal per hour and the lines may be of any length up to 5000 feet. The bulletin illustrates the system and its method of application. 8 pages, 8½x11—Fuller Lehigh Company, 85 Liberty Street, New York City.

Pulverized Fuel Equipment

Bulletin No. 7 "It Pays to Pulverize," describes Warrior Unit Pulverizers and Burners for application to steam boilers, oil stills, driers and kilns. The mill unit is self-contained and requires no dryers, additional fans, conveyors, separators or other motor driven equipment. One motor feeds the fuel, pulverizes it and delivers it to the burners and furnace irrespective of moisture condition. 8 pages and cover, 8½x11—Fuel Efficiency Engineering Corporation, Birmingham, Alabama.

Steam Flow Measurement

"The Handbook of Steam Flow Measurement" by L. K. Spink is a comprehensive presentation of the subject of steam flow and flow meters. The booklet presents an excellent technical analysis of the subject and is replete with tables, formulas and charts. This booklet will prove of value to any engineer who is interested in steam flow problems. 48 pages and cover, 5¼x7¾—The Foxboro Company, Foxboro, Mass.

Steam Generator Unit

The Fifth Boiler Unit installed at the Kips Bay Station of the New York Steam Corporation is described in a reprint of a technical article. This unit, which represents the most modern practice in the design of steam generating equipment and pulverized fuel firing, has been operated at ratings equivalent to 1,000,000 lb. of steam per hour. Numerous illustrations show details of construction. An interesting diagram is included to show the water circulation through the boiler and water-cooled furnace tubes. 12 pages, 8½x11—Combustion Engineering Corporation, 200 Madison Avenue, New York.

Steam Turbines

Bulletin 135-5 describes Coppus Steam Turbines designed to provide a highly efficient and reliable auxiliary drive turbine in sizes up to 60 hp. Comprehensive specifications and dimension tables are followed by fifteen performance curve charts which assist in determining the correct size of steam turbine for given conditions and the water rate for varying conditions of pressure, back pressure and superheat. 8 pages, 8½x11—Coppus Engineering Corporation, Worcester, Mass.

Testing Laboratory Service

"Fifty Years of Service to Industry" is the title of a new booklet just issued by Pittsburgh Testing Laboratory to describe the facilities and experience of that organization. The scope of this laboratory service extends to all phases of industry including inspection of equipment, fuel analysis and power plant testing. 32 pages and cover, 8½x11—Pittsburgh Testing Laboratory, Pittsburgh, Pa.

NOTICE

Manufacturers are requested to send copies of their new catalogs and bulletins for review on this page. Address copies of your new literature to

COMBUSTION
200 Madison Ave., New York

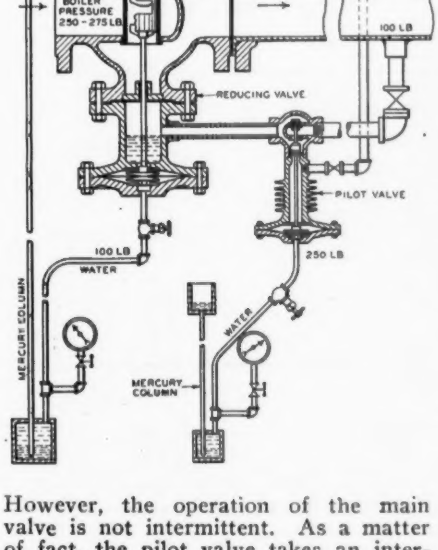
NEW EQUIPMENT

of interest to steam plant Engineers

Reducing Valve Limits Drop in Initial Pressure

The Mercon Regulator Company, One La Salle Street, Chicago, has developed a control system in which a pilot valve is applied to the standard Mercon reducing valve as indicated in the accompanying drawing. The purpose of this arrangement is to prevent the passage of steam through the reducing valve when the initial pressure drops below a predetermined minimum. The reducing valve does not close off completely but only enough to prevent the lowering of the initial pressure below a fixed minimum which may be required for the operation of turbo-generators or other equipment. The operation of this control system can be best understood from a typical application such as an industrial plant in which a part of the steam generated is used at high pressure for developing power, operating pumps, etc., the balance of the steam being used at a very much lower pressure for manufacturing processes throughout the plant. Under these conditions the demand for steam in the low pressure system may, at times, be so great as to reduce the higher pressure to a point below the satisfactory operating range of the high pressure equipment.

With the arrangement illustrated, the main reducing valve would gradually close under these conditions and thus prevent the demands of the low pressure system from lowering the boiler pressure beyond a predetermined minimum.



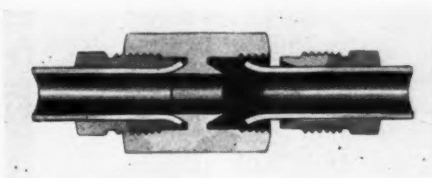
However, the operation of the main valve is not intermittent. As a matter of fact, the pilot valve takes an intermediate position when the supply steam pressure reaches 250 lb. and just enough pressure is applied to the upper surface of the main regulator diaphragm to close it down to a point where the 250 lb. inlet pressure is maintained.

Many applications of the device are possible as, for instance, two pressure boiler plants where the surplus high pressure steam may be passed through the reducing valve to the lower pressure system but where excessive demands of the low pressure system cannot reduce the high pressure below a predetermined minimum.

Compression Fittings And Tubing

The need for leak-proof and trouble-free small service lines in the power plant and industrial field has long been felt. Recently the Bailey Meter Company, Cleveland, Ohio, announced that Dieform Compression Fittings and Tubing are now available for this service.

The accompanying sectional view of a Dieform Tubing Union illustrates the method in which the joint is made. The



left-hand side of the tubing union is shown with the tube in place and the tube nut screwed down tightly to complete the metal-to-metal joint, while the right-hand side shows the tube nut unscrewed and slipped back along the tubing, which in turn is removed a slight distance from the seat in the fitting. This illustration shows how the tubing is securely gripped between the seat in the center fitting and the seat on the tube nut, resulting in a perfectly tight, dry, permanent joint.

In flaring the tubing the Dieform Nut serves as a die thereby assuring a perfect seat with the angle properly proportioned to the size of the tube. The moderate angle of flare prevents the tube from splitting or cracking and also permits the use of hard drawn tube when desirable.

Brass, Monel Metal or Steel Dieform Compression Fittings and Copper or Steel Tubing are especially well suited for piping where many bends must be made in the line and where an absolutely tight installation is required for high pressure and high temperature service. With these materials, perfectly tight metal-to-metal joints may be quickly made by an inexperienced laborer without thread compound, dies or tools other than a hammer and flaring tool. Joints made in this manner will resist vibrational strains as well as the strains resulting from the expansion and contraction of the tube caused by intermittent temperatures. Due to the reduction in the number of joints, installation of this material can be made in approximately one-half the time required for an equivalent rigid pipe installation.

Double extra heavy brass fittings with extra heavy soft annealed or half-hard copper tubing are suitable for pressures which do not exceed 800 lb. per sq. in. and where the intermittent temperature are under 600 deg. fahr. Where higher intermittent temperatures are expected, steel or monel compression fittings are recommended. Steel tubing should be used for pressures in excess of 800 lb. per sq. in. if the installation is subject to steam temperatures at intervals, although for hydraulic lines extra heavy copper tubing is satisfactory for pressures up to 2,000 lb. per sq. in.

Dieform Fittings and Tubing are recommended for all small piping, such as connections to metering and control equipment, and for water, oil, steam, compressed air and gas lines.

New Indicating Pyrometer Controller

The new Brown Model 1001-8 Indicating Pyrometer Controller illustrated can be supplied as an automatic control pyrometer, resistance thermometer, tachometer, or CO_2 meter.

The outstanding advantages of this instrument are:

1 Reading observed directly on 6 in. scale.
2 Index on scale for setting to exact control point.
3 Control point instantly and easily adjustable.
4 All wiring terminals and motor enclosed. No danger when used in the presence of explosive or inflammable gases.
5 Mercury switches up to 30 amperes capacity, eliminating the necessity of relay equipment. Make and break occurs in sealed glass tube. No danger of spark causing explosion.
6 Suitable for "on and off" or "three position" control through switches, valves, dampers, etc.
7 Available with patented safety device which opens furnace circuit if thermocouple or wiring fails, preventing burning out furnace.
8 High internal resistance, insuring accuracy.
9 Automatic internal compensation eliminating cold junction errors when instrument is supplied as a pyrometer.
10 Simplicity and ruggedness insures minimum of attention.

The control mechanism of Model 1001-8 Indicating Pyrometer Controller combines the basic principle of the Brown Auto-

matic Control Recorder with the new feature of mercury contacts for breaking high currents. Since these mercury switches are sealed in glass, all hazards due to open breaking of circuits in the presence of explosive or inflammable vapors, are eliminated.

Boiler, Stoker and Pulverized Fuel Equipment Sales

BOILER SALES

Orders for 516 boilers were placed in February, according to reports submitted to the Bureau of the Census by 74 manufacturers.

Month	1930 Number	1930 Square feet	1931 Number	1931 Square feet
January	942	1,081,749	598	576,723
February	873	938,906	516	622,343
Total (2 mo.)	1,815	2,020,655	1,114	1,199,066
March	977	1,263,709		
April	1,017	1,070,093		
May	1,283	1,329,748		
June	1,360	1,588,553		
July	1,309	1,410,096		
August	1,371	1,356,751		
September	1,254	1,282,388		
October	1,189	851,525		
November	777	709,322		
December	814	587,053		
Total (Year)	13,166	13,469,893		

TOTALS FOR FIRST 2 MONTHS AND NEW ORDERS, BY KIND, PLACED IN FEBRUARY, 1930-1931

Kind	1930 No.	1930 Sq. ft.	1931 No.	1931 Sq. ft.	February, 1930 No.	February, 1930 Sq. ft.	February, 1931 No.	February, 1931 Sq. ft.
Stationary: Total	1,764	1,814,263	1,080	1,090,062	859	930,104	495	526,947
Water tube	168	862,725	118	545,054	90	440,611	56	281,202
Horizontal return tubular	138	201,342	72	91,045	67	109,077	36	40,311
Vertical fire tube	207	70,274	119	32,357	89	32,935	60	17,163
Locomotive (not railway)	23	14,934	9	5,136	13	7,540	2	886
Steel heating [1]	964	427,075	631	297,274	460	212,850	276	127,367
Oil country	149	166,663	79	88,151	64	74,483	42	46,691
Self contained portable [2]	88	59,460	42	23,121	60	43,720	20	11,829
Miscellaneous	27	11,790	10	7,924	16	8,888	3	1,498

[1] As differentiated from power.
[2] Not including types listed above.

MECHANICAL STOKER SALES

March stoker sales, reported to the Bureau of the Census by the 11 leading manufacturers, totaled 63 stokers of 17,993 hp.

Year and Month	TOTAL No.	TOTAL H.P.	INSTALLED UNDER Fire-tube boilers No.	INSTALLED UNDER Fire-tube boilers H.P.	INSTALLED UNDER Water-tube boilers No.	INSTALLED UNDER Water-tube boilers H.P.
1929						
January	97	42,392	36	5,835	61	36,557
February	80	31,554	26	3,933	54	27,621
March	117	42,432	42	6,369	75	36,063
Total (3 Mo.)	294	116,378	104	16,137	190	100,241
Total (Year)	1,716	599,585	706	102,515	1,010	497,070
1930						
January	53	13,198	24	2,872	29	10,326
February	73	22,648	26	3,732	47	18,916
March	89	32,403	45	6,128	44	26,275
Total (3 Mo.)	215	68,249	95	12,732	120	55,517
April	108	35,903	46	6,984	62	28,919
May	96	31,956	41	5,703	55	26,253
June	151	47,803	70	10,100	81	37,703
July	150	37,761	83	11,434	67	26,327
August	115	29,988	61	10,587	54	19,401
September	128	42,899	71	9,186	57	33,713
October	92	38,276	46	5,148	46	33,128
November	71	21,103	41	5,731	30	15,372
December	53	11,726	35	5,307	18	6,419
Total (Year)	1,179	365,664	589	82,912	590	282,752
1931						
January	85	25,902	40	6,719	45	19,183
February	67	14,249	37	5,326	30	8,923
March	63	17,993	27	4,509	36	13,484
Total (3 Mo.)	215	58,144	104	16.554	111	41,590

PULVERIZED FUEL EQUIPMENT SALES

February orders for coal pulverizers as reported to the Bureau of the Census aggregated 8 pulverizers having a total capacity of 66,250 lb.

Year and Month	STORAGE SYSTEM PULVERIZERS Total Number	No. for new boilers, furnaces and kilns	No. for existing boilers	Total capacity lb. coal/hr. For contract	Total capacity lb. coal/hr. Based on New River coal, 3% moist	BOILERS Number	Total sq. ft. steam generating surface	Total lb. steam per hour equivalent	DIRECT FIRED OR UNIT SYSTEM PULVERIZERS Total Number	No. for new boilers, furnaces and kilns	No. for existing boilers	Total capacity lb. coal/hr. For contract	Total capacity lb. coal/hr. Based on New River coal, 3% moist	BOILERS Number	Total sq. ft. steam generating surface	Total lb. steam per hour equivalent
FOR INSTALLATION UNDER WATER-TUBE BOILERS																
1931																
January	2	2	..	60,000	88,000	1	51,177	704,000	8	4	4	40,500	55,300	9	42,970	412,675
February	1	..	1	40,000	50,000	1	29,100	375,000	2	2	..	8,000	8,500	1	7,570	75,000
Total (2 mo.)	3	2	1	100,000	138,000	2	80,277	1,079,000	10	6	4	48,500	63,800	10	50,540	487,675
FOR INSTALLATION UNDER FIRE-TUBE BOILERS																
1931																
January	..	..	..	......	......	..	......	....	6	..	6	6,000	6,750	6	7,500	53,350
February	..	..	..	......	......	..	......	....	3	..	3	2,250	2,250	3	3,000	22,350
Total (2 mo.)	..	..	..	......	......	..	......	....	9	..	9	8,250	9,000	9	10,500	75,700